Paddle River Dam
Probable Maximum Flood

FEBRUARY 2002

Alberta Environment

Environmental Assurance
Environmental Operations Division
Hydrology Branch
Surface Water Section

Paddle River Dam
Probable Maximum Flood

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February 2002

Alberta Environment

EXECUTIVE SUMMARY

The Paddle River Dam is an earth-filled structure located approximately 110 km northwest of Edmonton near the Town of Mayerthorpe. The primary function of the dam is to provide flood control to the mainly agricultural areas downstream in the lower Paddle River basin. The dam has a maximum height of 35 m and a top of dam elevation of 709.5 m. Water is passed through the structure via an outlet conduit that has a maximum capacity of 85 m^3/s. The chute spillway cannot be operated, instead being designed to spill uncontrolled when reservoir levels exceed the spillway crest elevation of 704.3 m. The maximum capacity of the spillway is 800 m^3/s. Construction of the dam began in 1981 and was completed in 1985. Full operations commenced in 1986.

The dam was designed to safely pass the design Probable Maximum Flood (PMF) of 858 m^3/s. The Hydrology Branch of Alberta Environment derived the original PMF estimate in 1985. Since the construction of the dam, there have been two large runoff events that were of a magnitude previously not recorded in the watershed. As part of a regular 5-year review of the dam, it was deemed prudent to investigate whether the 1985 PMF estimate remained valid. This report documents the 2000 update of the Paddle River Dam PMF.

The computed Probable Maximum Precipitation (PMP) was derived using World Meteorological Organization (WMO) guidelines. The PMP was applied to a calibrated SSARR (Streamflow Synthesis and Reservoir Regulation) Model to obtain the PMF estimate. The computed PMP is 362 mm over 48-hour duration. The resulting PMF peak is 1,890 m^3/s. Although it is possible that the potential effects of storage and overbank flow along the channel could act to mitigate this peak, further detailed hydraulic modelling would be required in order to undertake an analysis of the channel capacity and the resulting impact of channel storage. Under these conditions, this assessment is considered to be conservative.

ACKNOWLEDGEMENTS

The author wishes to acknowledge the following individuals for their contributions to the Paddle River Dam Probable Maximum Flood Study:

Sean Douglas	For providing his accumulated experience and knowledge derived from having completed the PMF Study for Dickson Dam. Special thanks for developing a rational approach to the SSARR Model calibration process.
Andy DeBoer	For conducting a technical peer review of the study.
Elliot Kerr	For generating the maps used in the report.
John Taggart	For mentoring and guidance, and for the final review of the document.

TABLE OF CONTENTS

TABLE OF CONTENTS (CONTINUED)

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS AND CONVERSION FACTORS

Metric units of measurement are preferred and have been used wherever possible. In some circumstances, such as displaying output from the SSARR model, it is more convenient to display U.S. Imperial units since those are the units used by the model.

Abbreviations

cubic metres per second	m^3/s or cms
cubic metres per second per square kilometre	$m^3/s/km^2$
cubic decametres	dam^3
millimetres	mm
metres	m
square kilometres	km^2
kilometres	km
millibars	mb
cubic feet per second	cfs
cubic feet per second per square mile	cfs/sq.mi.
acre-feet	ac-ft
feet	ft
square miles	sq.mi.

Conversion Factors

cubic metres per second	×	35.3146	=	cubic feet per second
cubic metres per second per square kilometre	×	91.4646	=	cubic feet per second per square mile
cubic decametres	×	0.8107	=	acre-feet
millimetres	×	0.03937	=	inches
metres	×	3.28083	=	feet
square kilometres	×	0.38610	=	square miles
kilometres	×	0.6215	=	miles

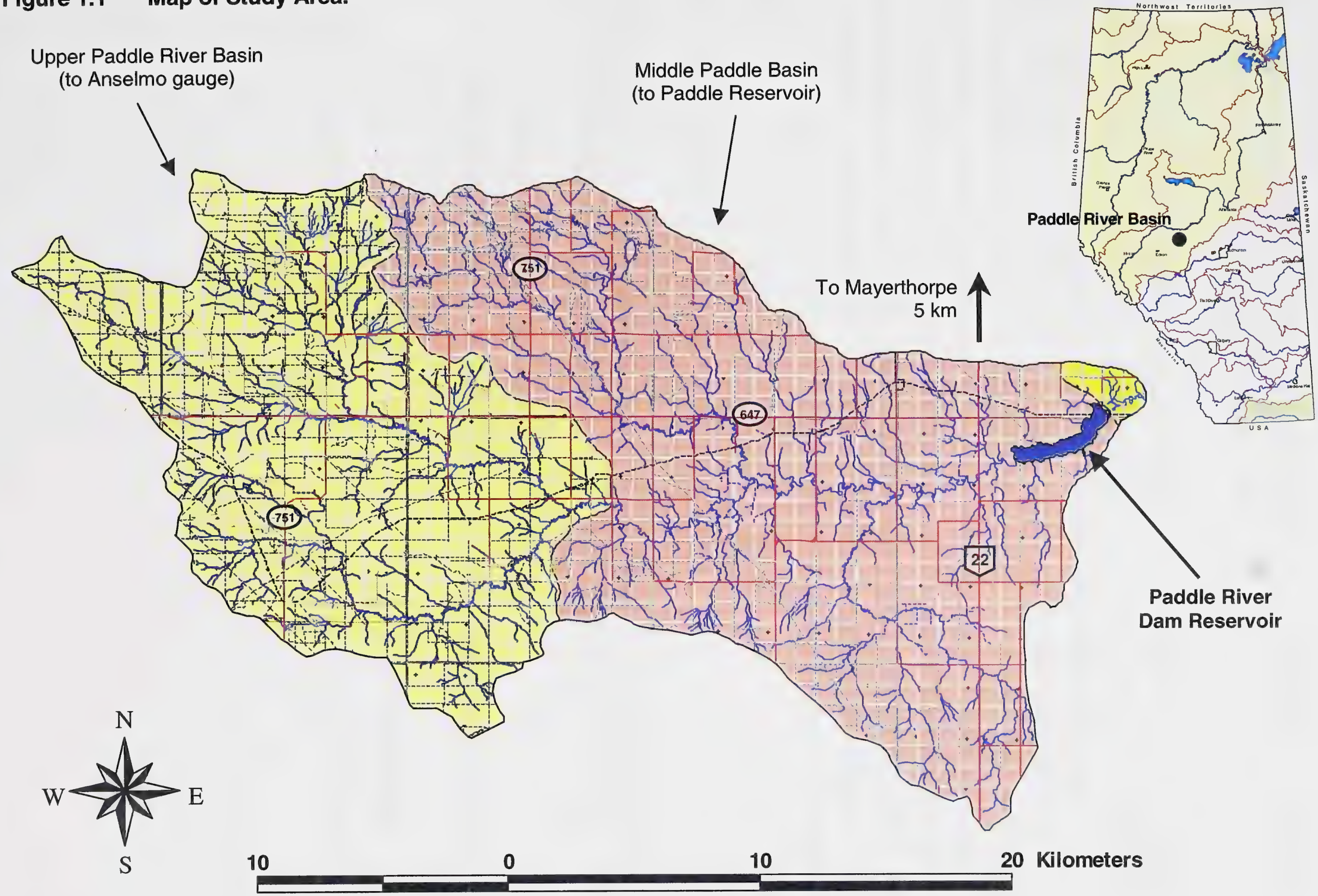
1.0 INTRODUCTION

1.1 Background

The Paddle River Dam is located in west-central Alberta approximately 110 km northwest of Edmonton, near the Town of Mayerthorpe. It is an earth-filled structure approximately 35 m high with a crest length of 625 m and top width of 8 m. The top of dam elevation is at 709.5 m. The main purpose of the dam is to provide flood control to the mainly agricultural areas downstream in the lower Paddle basin. Construction on the dam began in 1981 and was completed in 1985. Other than releases through the outlet conduit, the dam cannot be operated. The spillway is an uncontrolled chute spillway and discharges freely when levels in the reservoir exceed the elevation of the spillway crest at 704.3 m. The maximum capacity of the spillway is rated at 800 m^3/s, while the conduit outlet has a maximum capacity of 85 m^3/s. Refer to Figure 1.1 for a map of the study area.

The Hydrology Branch of Alberta Environment previously completed two Probable Maximum Flood (PMF) estimates for the Paddle River Project. An initial PMF was prepared in 1977, as part of a general hydrology report for the Project area, using a fitted U.S. Soil Conservation Service type hydrograph. The value of 671 m^3/s (23,700 cfs) was subsequently re-estimated on a more detailed basis in 1978, although no formal report was prepared. The updated estimate used a more peaked distribution of the PMP and incorporated the use of SSARR (Streamflow Synthesis and Reservoir Regulation) modelling to shape the final PMF hydrograph. The 1978 estimate was determined to be 858 m^3/s (30,300 cfs) for a PMP of 344 mm (13.55 inches) and storm duration of 48 hours. In 1984, a request was received from the Paddle River Dam Review Board to prepare a short technical report to document the derivation of the 1978 PMF, presumably to confirm the final sizing of the structure as construction on the dam progressed. The Hydrology Branch subsequently issued a “Paddle River Dam Probable Maximum Flood Addendum” in December of 1985 detailing the 858 m^3/s estimate. The spillway capacity, rated at a maximum 800 m^3/s, was designed to pass the routed PMF. Since that time, a high-yielding runoff event in the

Figure 1.1 **Map of Study Area.**



watershed occurred in 1989, suggesting that an update to the original PMF was warranted to ensure that the 858 m^3/s inflow value remained valid.

For the purposes of this study, the 1978 PMF estimate of 858 m^3/s will be referred to as the 1985 Study, since the only formal report documenting the previous PMF was the addendum produced in 1985. Derivation of the present PMF will follow a similar procedure as the previous report and other recent PMF studies that have been completed by the Hydrology/Forecasting Section of Alberta Environment. The Probable Maximum Precipitation is calculated using the World Meteorological Organization (WMO) procedure of storm maximization based on ratios between observed storm dew points and the 1:100 year persisting dew points in the region. Once the PMP is determined, the rainfall is distributed and applied to a calibrated SSARR basin model for runoff and routing to the reservoir. This simulated basin response from the PMP input provides the Probable Maximum Flood for the dam.

1.2 Objectives

The objective of this study is to provide the Probable Maximum Flood for the Paddle River Dam near Rochfort Bridge. Specifically, this report will document the following items:

- The derivation of the PMP for the basin above the dam;
- Details of the calibration and final calibrated watershed model for the Paddle River basin above the Paddle River Dam;
- The derived PMF for the Paddle River Dam using the calibrated SSARR Model; and
- A comparison of the updated PMF value to the previously derived value of 858 m^3/s.

2.0 HYDROLOGY OF THE PADDLE RIVER WATERSHED

2.1 Watershed Description

The Paddle River Reservoir watershed is located mainly in the dry mixedwood region of Alberta with the headwater area in the lower foothills region. The basin drains an area of approximately 620 km^2 (240 sq.mi.), originating in the hills north of Chip Lake and east of the McLeod River. The terrain is marked by predominantly rolling terrain and generally mild topographic relief, with elevations in the basin upstream of the dam ranging from 990 m (3250 ft) near the headwaters to 685 m (2250 ft) at the dam. The headwater region above Anselmo is characterized by mainly forested areas of aspen, poplar and spruce boreal forest with some agriculture, while land use in the lower basin is generally agricultural in nature with areas of aspen boreal forest. Soils are moderately well-drained gray luvisols. Downstream of the dam, the Paddle River continues in an east-northeasterly direction, past the Town of Barrhead and into the Pembina River, which eventually flows into the Athabasca River.

For the purposes of modelling, the watershed upstream of the reservoir was treated as a single lumped watershed. A Water Survey of Canada (WSC) gauge near Anselmo (07BB011) is located upstream of the dam and divides the basin roughly in half, however, the decision to treat the basin as a single watershed was based primarily on poor data availability at Anselmo for the two highest events of record. Due to the relatively small basin size and the available calibration data, there would be no benefit derived from modelling two separate watersheds. A second WSC gauge is located approximately 2.4 km downstream of the dam, near Rochfort Bridge (07BB004). This gauge has been operational since 1963, however, since the construction of the dam this gauge effectively measures total outflow from the reservoir. The gauge near Anselmo was installed in 1980, and flows at that location are considered natural. A summary and the associated drainage areas are presented in Table 2.1. Refer to Figure 2.1 for a map of the study area showing topographic information and the location of the various hydrometric and meteorologic data collection sites that were used in this study.

Figure 2.1 Relief Map of Paddle River Basin with Streamflow and Climate Stations.

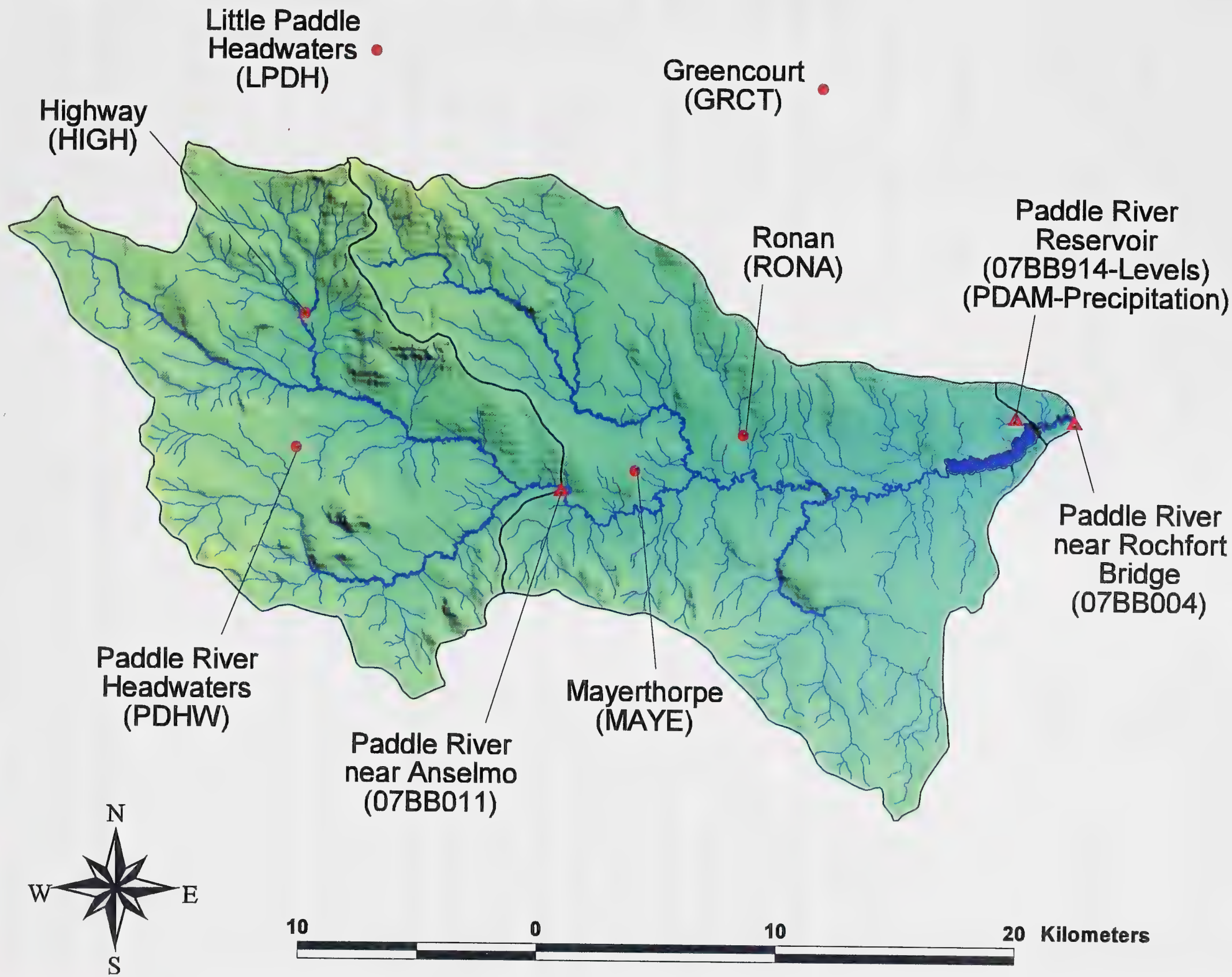


Table 2.1 **Drainage Areas of Gauges and Sub-basins of Interest for the Paddle River Dam.**

Gauging Location or Sub-basin Area	Drainage Area	
Paddle River near Anselmo – WSC 07BB011	261.1 km^2	
Paddle River from Anselmo gauge to Dam	359.3 km^2	
Total Paddle River Drainage Area to Paddle River Dam		**620.4 km^2**
Paddle River near Rochfort Bridge – WSC 07BB004	625.0 km^2	

2.2 Hydrologic Characteristics

The Paddle River basin above the dam averages approximately 525 mm in mean annual precipitation. Of this total, roughly three-quarters (405 mm) occurs as rainfall, while the remainder (120 mm) occurs as snow. Mean annual evapotranspiration (the combination of evaporative losses plus transpiration of water to the atmosphere from vegetation) is about 385 mm per year. The mean annual runoff for the basin is around 95 mm. The remaining portion of the mean annual water balance (45 mm) is considered to be lost through a combination of the sublimation of the snowpack and through groundwater recharge. The majority of runoff occurs during the April to July period. As is shown in Figures 2.2 and 2.3, the mean monthly hydrographs near Anselmo and near Rochfort Bridge show similar patterns in seasonal streamflow, with a large volume occurring in April during spring runoff, followed by relatively high volumes in June and July in response to summer precipitation. During the late summer period starting in August, the majority of the active storm season has passed and the hydrograph begins to decline into the fall period. Also of interest is the persistence of flow that is noted well into the late fall period. Although year-round discharge cannot be confirmed since flow is not measured during the winter months, the late-season persistence suggests that groundwater plays a significant role in the watershed and maintains baseflow during the winter.

The timing of the spring runoff is typically in early April and generally concludes by the middle to latter part of that month, with an average duration of about 2-3 weeks. Spring runoff can occur as early as mid-March and has ended as late as mid-May (as occurred in the record snowpack year of 1974). After the spring period, hydrograph response is

Figure 2.2 **Mean Monthly Discharge Range–Paddle River near Anselmo (1980-1999).**

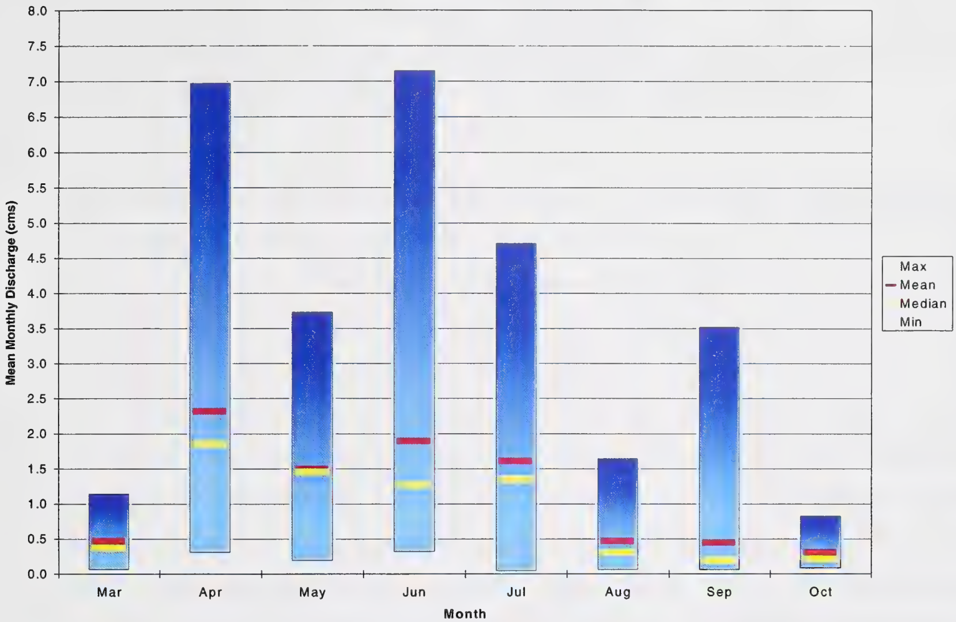
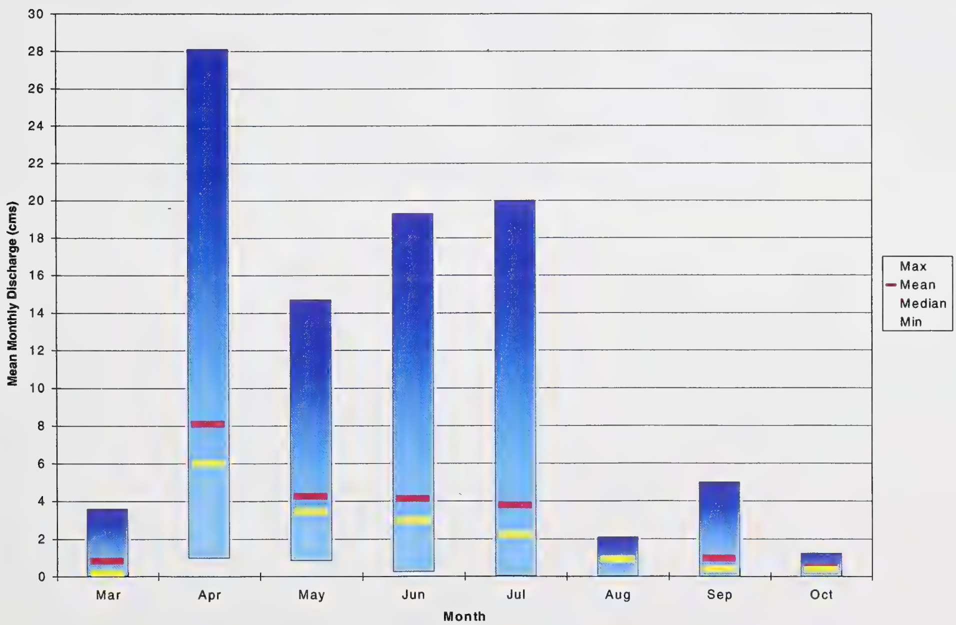


Figure 2.3 **Mean Monthly Discharge Range–Paddle River near Rochfort Bridge (1963-1983).**



dominated by summer rainfall events, with runoff from major storms typically lasting for 6-8 days and the hydrograph peak occurring within 1-2 days of the beginning of the event. The top flood events on record (1989, 1986, 1990) have all occurred in the July to early August period as a result of summer rainfall. The annual flood peak is generally governed by a summer storm (in roughly 5 out of 6 years), rather than the spring runoff event.

At the time of the first PMF report, the WSC gauge near Rochfort Bridge had been in operation for about 15 years, 1963-1977. The event of record at that site (135 m^3/s) occurred in 1965, with the second largest peak discharge being the 1974 snowmelt event (91.7 m^3/s). Since the construction of the dam, there have been two events at the Anselmo gauge (in 1989 and 1986) that were of a magnitude not previously recorded in the basin. The peak yields for those events at the upper basin were up to four times as large as those measured prior to 1983 downstream near Rochfort Bridge. Although direct comparisons are not possible since the drainage area at Anselmo is less than half that of the Rochfort Bridge site, the events peaks can be estimated by routing the outflow from the dam back through the reservoir to determine the inflow hydrograph. Using this technique, the 1989 event was at least twice as large as the previous peak event of 1965 at the Rochfort Bridge gauge. For reference, note that the original PMF value of 858 m^3/s is equivalent to 1.38 $m^3/s/km^2$ (126 cfs/sq.mi.), slightly less than double the estimated 1989 peak yield at Anselmo. Table 2.2 lists the three largest runoff events for various watersheds and the peak yields. The Little Paddle River near Mayerthorpe (07BB005) drains an area of 297.8 km^2 and has also been included in the table. The Little Paddle River, located immediately to the north of the Paddle River watershed, is very similar in its characteristics and has a longer continuous period of record available for the comparison of historical flood peaks.

Table 2.2 Largest Recorded Events in the Paddle River and Local Watersheds.

Location and Period of Record	Year	Peak (m^3/s)	Yield ($m^3/s/km^2$)
Paddle River near Rochfort Bridge (07BB004) 1963-1983 (regulated since 1983)	1965	135 R	0.22
	1974	91.7	0.15
	1978	83.0	0.13
Paddle River near Anselmo (07BB011) 1980-1999	1989	225 E	0.86
	1986	110	0.42
	1990	71.2	0.27
Paddle River Reservoir Inflows (Estimated by backrouting outflow through reservoir.)	1989	258	0.42
	1986	99.9 Q	0.16
	1990	100	0.16
Little Paddle River near Mayerthorpe (07BB005) 1963-1999	1989	150	0.50
	1965	85.9 R	0.29
	1971	84.4	0.28

E – Peak estimated by WSC.

R – Peak estimated using regression analysis against recorded maximum daily discharge.

Q – Best estimate only; data is of lesser quality.

3.0 PROBABLE MAXIMUM PRECIPITATION

3.1 Definition of Probable Maximum Precipitation

Probable Maximum Precipitation (PMP) is defined as the greatest depth of precipitation for a given duration that is meteorologically possible for a given basin at a given time of year, with no allowances made for long-term climatic trends (WMO, 1973). For this study, a meteorological approach is used for the computation of the PMP. This method allows for the transposition and maximization of similar storms that have not necessarily occurred near or within the study area, but can be reasonably expected to occur in the Paddle River basin. The method is therefore indirect, but justified by the relatively short-term meteorological records that exist in the region. Calculation of the PMP will follow WMO guidelines as detailed in the following Sections.

3.2 Meteorology of Major Storms

Precipitation and streamflow data for the Paddle River Basin indicate that the season for most major storm events is during the months of June and July, when meteorological conditions are the most favourable. The general synoptic conditions that produce these major storms are fairly consistent. By June, the southern half of the United States and all of the Gulf of Mexico have warmed appreciably, substantially increasing the capability of the air masses over these regions to carry moisture. These moisture-laden air masses begin to spread over the Great Plains towards the eastern slopes of the Continental Divide in a north-northwesterly direction, reaching areas of relatively cooler air in the north without any substantial upwind moisture depletion. This inflow of moist Gulf Coast air is further enhanced by one or more cold low systems off the Pacific coast in the Gulf of Alaska, which begin tracking eastward across British Columbia and Washington State. During the early summer, these cold low systems have lost little of their late winter and early spring energy, and the warm, moist Gulf air becomes involved in an energetic counterclockwise circulation around these low-pressure systems. The convergence around the cold low causes large quantities of moisture to be released. In the foothills and Rocky Mountain regions of Alberta, the counter clockwise circulation causes the warm air mass to be forced upslope in a north-northeast direction, creating a further orographic component of precipitation as a result of the lifting and cooling of the air mass. Although the headwaters of the Paddle River

basin lie in the lower foothills, the orographic component of the PMP would not be significant, given the relatively mild basin relief (roughly 300 m or 1000 ft elevation differential, over a basin length of about 45 km).

3.3 Convergence PMP

The Oldman River Dam PMF Study (Bothe et. al., 1985) maximized seven major convergence storms applicable for the Province of Alberta. An enveloping procedure was applied for all storms and all durations to determine the largest covergence-type storm event to be used in the PMF analysis. The rainfall event of June 15, 1973 (ALTA-6-1973, Storm Center A) was found to be the largest convergence type storm for Alberta. This event is meteorologically transposable to the Paddle River basin. In terms of temporal transposition, it is assumed that the event could have occurred 15 days prior or after the actual date of the storm. A maximization of the 1989 storm that produced the event of record on the Paddle River was not undertaken. However, a cursory examination of the recorded rainfall indicates that the roughly 140 mm that occurred over a 24-hour period would likely not supercede the 1973 event in terms of severity. Therefore, the 1973 storm was adopted for maximization in this study.

3.3.1 Maximum Persisting Dew Points

Surface dew point temperatures in the vicinity of the study area are of reasonable length (slightly less than 50 years at Edmonton and Whitecourt), and are generally of high quality, with hourly temperature and humidity data available for most of the period of record. The 1:100 year, 12, 24, 36 and 48-hour persisting dew points will be used as indicators of the maximum atmospheric moisture. The maximum persisting dew points were calculated on a semi-monthly basis for the specified durations for the May to September period. Three sites were selected based on their proximity to the study area: Edmonton Municipal Airport, Whitecourt and Edson. In order to directly compare the reference sites, the calculated surface dew point temperatures were pseudo-adiabatically reduced to 1000 mb pressure, 0 m elevation (sea level). The data from these sites were then fitted to a normal frequency distribution to determine the 1:100 year values. Average values for the Paddle basin were derived based on the approximate distance from the three reference sites. Refer to Appendix 1 for additional details. The final values are presented in Table 3.1.

Table 3.1 1:100 Year Persisting Dew Point Temperatures (°C) at 1000 mb and 0 m Elevation for the Paddle River Basin.

Persisting Dew Point	Time of Year									
	May 1-15	May 16-31	Jun 1-15	Jun 16-30	Jul 1-15	Jul 16-31	Aug 1-15	Aug 16-31	Sep 1-15	Sep 16-30
12 Hour	14.9	16.0	19.2	19.5	21.7	22.3	22.3	21.0	19.2	16.2
24 Hour	13.9	15.7	18.4	18.8	20.7	21.1	21.3	20.0	18.0	14.9
36 Hour	13.3	15.4	18.0	18.4	20.5	20.8	20.9	19.9	17.8	14.6
48 Hour	12.7	15.0	17.6	18.1	20.2	20.2	20.7	19.4	17.2	14.4

The values presented in this study are somewhat higher than the Oldman PMF for the 24 to 48-hour durations, but slightly less for the 12-hour persisting dew point temperature. They also tend to peak 15 days later than in the previous study, around the beginning of August as opposed to the latter half of July. The differences are deemed to be reasonable, given that the values for the Oldman PMF are based on a sampling of sites in the southern part of the Province, which is generally warmer earlier in the season, and remains drier throughout the summer months.

3.3.2 1000 mb Convergence PMP

The 1000 mb convergence PMP for the Paddle River basin is derived by examining the synoptic characteristics of upwind meteorologic stations for the 1973 storm. The storm is then maximized by comparing the actual synoptic conditions to the possible "worst-case" condition, which assumes the maximum amount of available moisture for that time of year based on the 1:100 year persisting dew point. The tabulated depth-area-duration values for the 1973 storm were examined and precipitation depths based on a 620 km^2 study area, for each 12-hour duration, were derived. Appendix 1 contains the detailed calculations for the storm maximization calculations. WMO procedure uses only the 12-hour maximum persisting dew point temperature over the entire storm duration of 48 hours (fixed dew point procedure), while the Oldman PMF Study used a variable dew point procedure that takes into account the temporal variability of dew point over time, hence the 12, 24, 36 and 48-hour persisting dew point calculation. The PMP was calculated using both approaches, as given in Tables 3.2 and 3.3 and as shown in Figure 3.1.

Table 3.2 **1000 mb Convergence PMP for a 620 km² Area by Fixed Dew Point Procedure.**

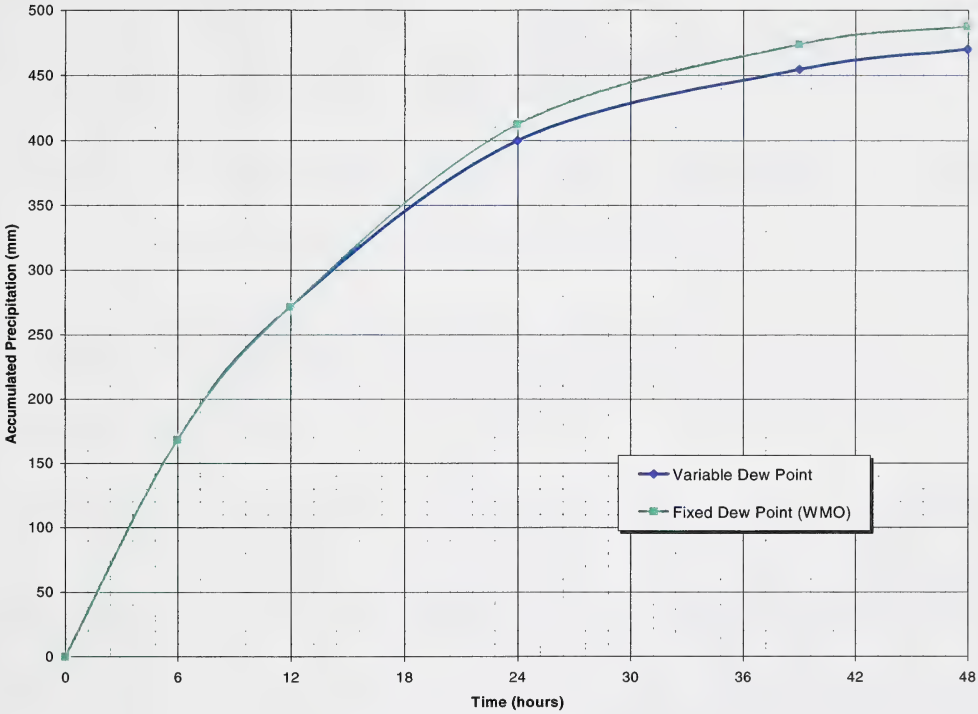
Hours	0-6	7-12	13-18	19-24	25-30	31-36	37-42	43-48
Accumulated PMP (mm)	169	271	352	412	445	465	481	488
Incremental PMP (mm)	169	102	81	60	33	20	16	7

Table 3.3 **1000 mb Convergence PMP for a 620 km² Area by Variable Dew Point Procedure.**

Hours	0-6	7-12	13-18	19-24	25-30	31-36	37-42	43-48
Accumulated PMP (mm)	169	271	345	400	429	446	462	470
Incremental PMP (mm)	169	102	74	55	29	17	16	8

As expected, the variable dew point procedure results in a slightly lower PMP value, since the maximum persisting dew point temperature declines incrementally over the length of the storm. The fixed dew point procedure is somewhat conservative and was derived based on the assumption that high quality, hourly dew point temperatures are not generally available. Given the relatively small difference between the two procedures, and since the variable dew point procedure is meteorologically more representative of how dew points actually vary with time, the variable persisting dew point procedure is adopted as the preferred method. Therefore, the calculated 1000 mb convergence PMP for the Paddle River Dam is 470 mm for a 48-hour duration, as given in Table 3.3.

Figure 3.1 Accumulated 1000 mb Convergence PMP for 620 km² Area.



3.3.3 Convergence PMP for SSARR Modelling

The convergence PMP as calculated in the previous Section is at the 1000 mb (sea) level. In estimating the PMP for elevations above sea level, the amount of moisture in the column of air must be depleted at the moist adiabatic laspe rate from the 1000 mb surface level up to the elevation where the convergence PMP is to be applied. The convergence precipitation at different elevations is calculated using the following equation:

$$P_{elev} = \frac{(T - x)}{T} \cdot P_{1000} \quad \text{..........} \quad (1)$$

Where P_{elev} = precipitation at a specific elevation above 1000 mb;

P_{1000} = precipitation at the 1000 mb elevation;

T = total precipitable water (mm) in a column of air between 1000 mb and the nodal surface (300 mb level) as a function of the 1000 mb dew point temperature; and

x = precipitable water (mm) between 1000 mb surface and indicated height above that surface in a pseudo-adiabatic atmosphere as a function of the 1000 mb dew point temperature.

The 1000 mb dew point temperatures used in the calculation of precipitable water (in T and x above) are the variable dew points (12, 24, 36, and 48-hour persisting dew points) calculated previously.

The proper procedure for depleting the 1000 mb PMP to the basin elevation is to separate the basin into elevation bands and then deplete the PMP to the average elevation for each band. The composite PMP is then calculated based on the relative area of each elevation band and its elevation-depleted PMP. This procedure was simplified somewhat for the Paddle River basin given the relatively low basin relief. Instead of using composite elevation bands derived from hypsometric curves, the depleted PMP was calculated at three different elevations: top of watershed (990 m); bottom of watershed at the dam (685 m); and at an assumed basin-average elevation (787 m). The basin-average elevation was estimated based on an assumption that 50% of the basin area lies within the lower 2/3 of the overall elevation difference in the watershed (see Figure 3.2). This assumption is more realistic than applying a simple linear relationship to the basin area-elevation curve, since watersheds generally have a smaller proportion of their total area in the relatively steeper headwater regions. As can be seen in Table 3.4, the resulting PMP amounts range from 342 mm (by applying the PMP to the top-of-watershed elevation) to 376 mm (by applying it to the minimum basin elevation). The relatively small difference of 34 mm between the resultant PMP estimates at the basin maximum and minimum elevations suggests that using the assumed basin average elevation will provide a reasonable value for the final convergence PMP. This methodology results in a final convergence PMP of 362 mm of 48-hour duration. The adopted convergence PMP values are given in Table 3.5.

Figure 3.2 Adopted Paddle Basin Hypsometric Curve.

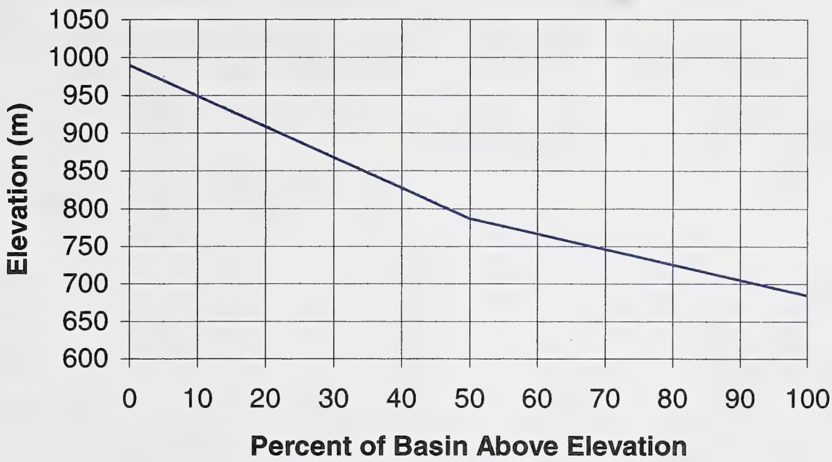


Table 3.4 Incremental Convergence PMP (mm) at Indicated Basin Elevation.

Elevation (ft) Elevation (m)	0 0	3250 990	2580 787	2250 685
Hours	**Probable Maximum Precipitation (mm)**			
0-6	169	123	131	136
7-12	102	74	79	82
13-18	74	54	57	59
19-24	55	40	42	44
25-30	29	21	22	23
31-36	17	12	13	13
37-42	16	12	12	13
43-48	8	6	6	6
Total Storm	470	342	362	376

Table 3.5 Adopted Convergence PMP for the Paddle River basin.

Hours	0-6	7-12	13-18	19-24	25-30	31-36	37-42	43-48
Accumulated PMP (mm)	131	210	267	309	331	344	356	362
Incremental PMP (mm)	131	79	57	42	22	13	12	6

3.4 Orographic PMP

The orographic component of the PMP is meant to take into account the effect of the warm air mass being forced upslope against the hills or mountains, causing additional precipitation to occur as a result of the lifting and cooling of the air mass. The orographic component is considered to be negligible in the Paddle River basin given the relatively mild basin relief. Other studies (Hansen et.al., 1988) suggest that a rough rule of thumb for the determination of upslopes suitable for orographic conditions is a representative elevation change of 1000 feet over a distance of 5 miles or less (300 m over 8 km or less). The Paddle River basin experiences an approximate elevation gradient of roughly 300 m over 45 km, with no indication that the elevation gradients are abrupt and would represent a significant upslope barrier. It is for these reasons that it was deemed that the calculation of the orographic precipitation component would not provide any greater accuracy or confidence to the overall PMP estimate, and therefore only the convergence component will be used in determining the PMP for the Paddle River basin.

3.5 Total PMP for SSARR Modelling

As outlined in Section 3.4, the final PMP for the Paddle River basin consists of the convergence PMP value of 362 mm as calculated on Section 3.3. The orographic component is negligible and therefore has not been calculated for this study. The final PMP values are given in Table 3.6. This value is 5% higher than the previous PMP value of 344 mm.

Table 3.6 Final Adopted PMP for the Paddle River basin.

Hours	0-6	7-12	13-18	19-24	25-30	31-36	37-42	43-48
Accumulated PMP (mm)	131	210	267	309	331	344	356	362
Incremental PMP (mm)	131	79	57	42	22	13	12	6

4.0 PROBABLE MAXIMUM FLOOD

4.1 Conversion of the PMP to the PMF

Section 4.0 details the assumptions and procedures used to convert the PMP for the Paddle River basin derived in Section 3.0 to a Probable Maximum Flood for the Paddle River Dam. The rainfall-runoff model chosen to simulate the basin response to the PMP is the U.S. Army Corps of Engineers “SSARR” (Streamflow Synthesis and Reservoir Regulation) basin model. The SSARR Model was selected based on its high degree of familiarity and common use within the Hydrology/Forecasting Section of Alberta Environment. The model consists of two major components: 1) a watershed model that is used to simulate rainfall-runoff and snowmelt-runoff processes; and 2) a river model for routing streamflow from upstream to downstream through river channels and lakes. Since the Paddle River above the dam was represented as a single basin, only the watershed portion of the model will be used in the calibrations.

4.2 Calibration of the SSARR Model

4.2.1 General Considerations

The general procedure in the calibration of any rainfall-runoff model is to select several runoff events and then best match the simulated results to the recorded data by optimizing model parameters. Relationships derived within the model should maintain a physical sense. Overall, the SSARR modelling process consists of four main components:

1) Determine total moisture input to the basin (rainfall, snowmelt).

2) Determine the soil moisture condition of the basin using a continuous water balance of precipitation, evaporation and runoff.

3) Determine the net moisture input available to generate runoff based on moisture input, soil moisture condition, and soil moisture versus runoff relationships.

4) Determine runoff based on the net moisture input and size of drainage area. Runoff is divided into three components: surface (fast), sub-surface (medium) and baseflow

(slow); each is routed separately through hypothetical linear reservoirs and combined to form the total hydrograph.

Although obtaining the best match for a wide range of flows is desired, the primary goal of calibration in this Study is to match as best as possible the highest peaks on record so that the basin response to higher order events is optimized for the PMF simulation. Recorded data from the Paddle River near Anselmo indicate that the highest rainfall-runoff events (in descending order) for the basin occurred on August 3, 1989; on July 18, 1986; and on July 4, 1990.

4.2.2 Consideration of Snow and Snowmelt in PMF Derivation

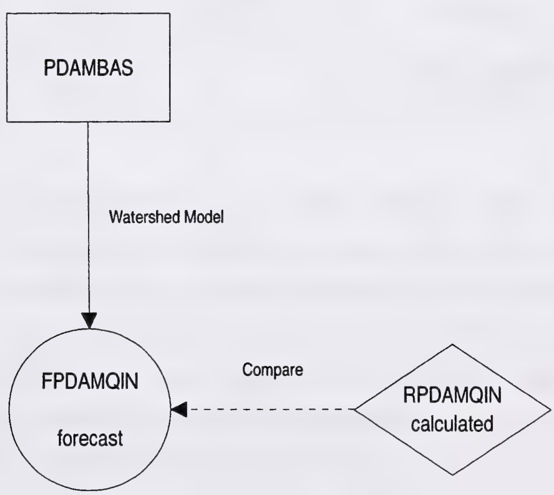
In general, each watershed in the SSARR model is represented by two “sub-watersheds”: a snow-free area and snow-covered area. Snow and snowmelt runoff was not considered in the calibration of the Paddle River basin since spring runoff is concluded long before the calibration periods for the peak runoff years of 1989, 1986 and 1990. All three of these events are exclusively the result of summer storms. In terms of the potential for snow and snowmelt to contribute to a PMF event, the decision to disregard snow as an input component is based on observed meteorology and hydrology in Alberta. The maximum elevation in the Paddle River basin is 3250 feet (990 m), which is well below the elevations at which snow might be expected to persist beyond the end of May. The possibility of a rain-on-snow type PMF event in the Paddle basin is unlikely due to the desynchronous timing of spring runoff and the occurrence of major convective-type frontal systems. As was observed in a year of record snowpack (1974), which is considered to be roughly the 1:100 year snowpack, spring runoff was concluded by the middle of May. Based on the seven major convective storms that were maximized in the Oldman Dam PMF Study, the earliest date of occurrence observed for these storms is around mid-June (as in the 1973 event). Since the general synoptic conditions that generate these large-scale, convective-type rainfall events have not yet been favourably established by early May, the probability of a rain-on-snow PMF event is greatly diminished.

4.2.3 SSARR Model

A simple schematic of the model is shown in Figure 4.1. The watershed information is contained in a single card denoted by PDAMBAS. The model generates a forecasted inflow to the dam, FPDAMQIN. This is compared to the recorded inflow to the dam RPDAMQIN, which is calculated separately based on the observed dam outflows (as measured by WSC gauge Paddle River near Rochfort Bridge) and the change in storage as obtained from recorded reservoir levels and the elevation-capacity relationship. The recorded dam inflows were generated using hourly streamflow and reservoir levels, within the Hydrol Modelling Platform. The SSARR model is run on a three-hourly time step.

In addition to recorded streamflow data, the SSARR model requires only recorded precipitation data since snow is not being considered. There are several meteorological stations that can be used for the Paddle River basin, as shown previously in Figure 2.1. Wherever possible, published daily data by Atmospheric and Environmental Services (AES) of Environment Canada was used, as the data is considered to be of very high quality. Several other real-time sites operated by Alberta Environment (AENV) were used to supplement the gauge network. This data is available on a 1-, 3-, or 6-hourly basis,

Figure 4.1 Schematic of the SSARR Model for Paddle Basin.



depending on the site, and was also used to distribute the AES daily data to a finer time step. Data sets from four stations were eventually used to establish a basin-average precipitation, weighted using Thiessen polygons. A single site, designated PAD2, was generated for SSARR to contain the basin-average precipitation. A summary of the precipitation data used is given in Table 4.1.

Table 4.1 Summary of Meteorological Stations and Data used in SSARR Model Calibrations.

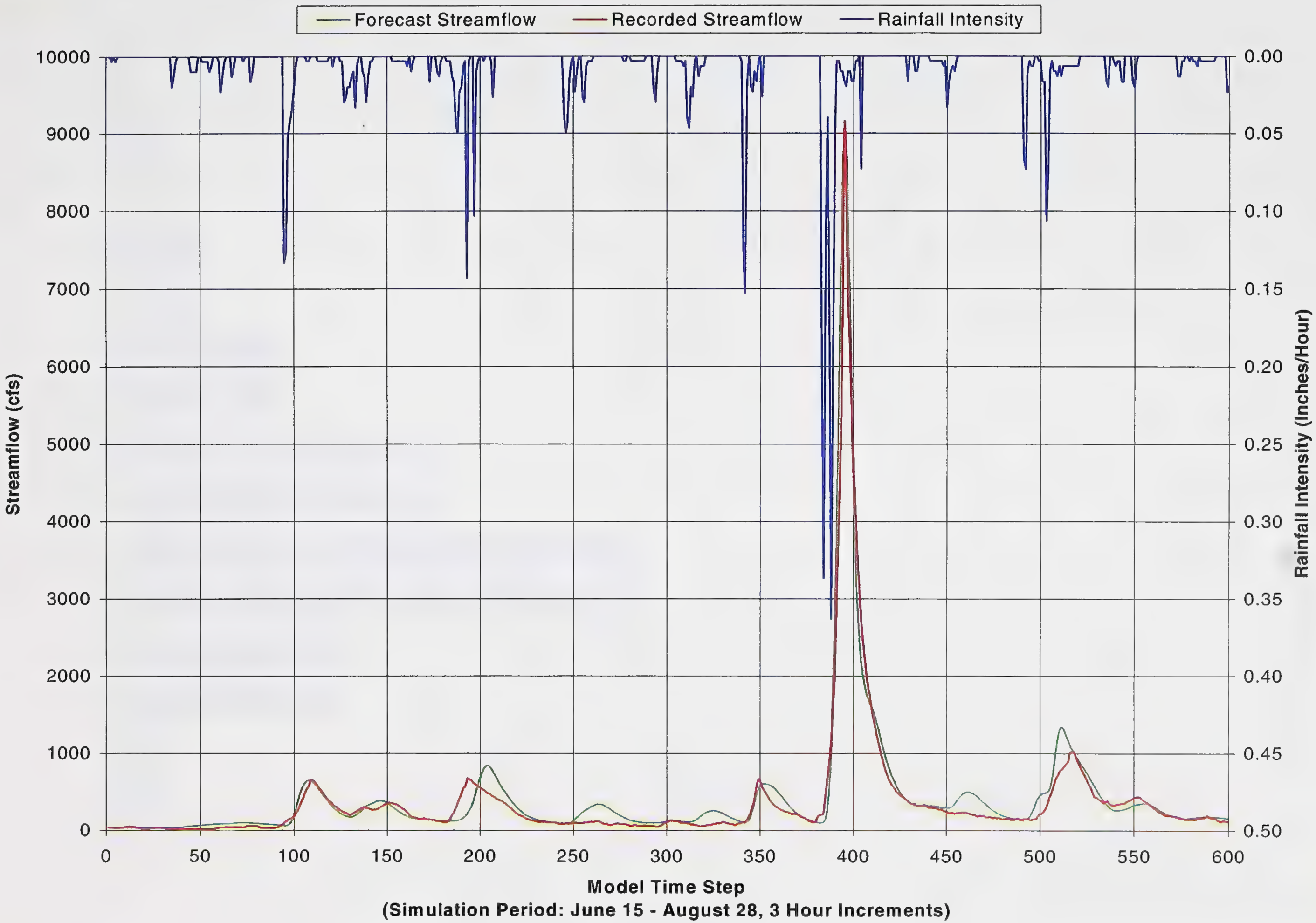
Station Name	SSARR Name	Type	Comment	Station Weight
Highway	HIGH	AES-Daily	Distributed using AENV-PDHW	46.2
Paddle River Headwaters	PDHW	AENV-Real-time	Not used directly	-
Ronan	RONA	AES-Daily	Distributed using AENV-MAYE	41.0
Mayerthorpe	MAYE	AENV-Real-time	Not used directly	-
Paddle River Dam	PDAM	AENV-Real-time		10.4
Little Paddle Headwaters	LPDH	AENV-Real-time		2.4
Greencourt	GRCT	AENV-Real-time	Not used	-
-	PAD2		Basin Average Precipitation	100.0

The selected years for model calibration are 1989, 1986 and 1990. Both reservoir and streamflow data for 1989 and 1990 are of good quality, resulting in high quality inflow hydrographs. Data for 1986 is of lesser quality due to the dam not being fully operational at the time of the July event. The reservoir had not yet been filled and was below the live-storage level, while the recorded levels, though they captured the major runoff event, are sporadic throughout the year and therefore the record is incomplete. The calculated inflow hydrograph for 1986 was used as a general indicator only.

4.2.4 Calibration Results

The final calibrated relationships for the SSARR modelling parameters governing soil moisture versus runoff, evapotranspiration, surface-subsurface flow separation, and baseflow infiltration are provided graphically in Appendix 2. A printout of the SSARR model text file is provided as reference in Appendix 3. Results for the event of record, 1989, are shown in Figure 4.2 and give a good representation of the modelling results. Similar graphs showing the final calibrated hydrograph to the recorded inflow hydrograph for each of the three years of simulation (1990, 1989, and 1986) are given in Appendix 4. Also included with those plots are the more detailed calibration results showing the separate surface, sub-surface and baseflow components that make up the final combined hydrograph. Note that recorded data for 1986 is considered to be of lesser quality.

Figure 4.2 Plot of 1989 Model Calibration (Recorded versus Simulated Paddle Dam Inflow).



5.0 DETERMINATION OF PROBABLE MAXIMUM FLOOD

5.1 Critical Shape of Rainfall Mass Curves

After calibration of the SSARR model is complete, the first step in applying the PMP to the basin is to determine the critical rainfall distribution that will result in the largest possible PMF within the bounds of a total PMP of 362 mm in a 48-hour period. As the PMP was determined in 6-hour increments, those increments will be distributed in a physically realistic manner so as to maximize the resultant PMF. The Chicago Distribution was used for an initial trial run, with variations attempted thereafter in a trial-and-error approach. The selected rainfall mass curve producing the highest runoff response is given in Table 5.1 and shown graphically in Figure 5.1.

Figure 5.1 Critical Rainfall Mass Curve for PMP.

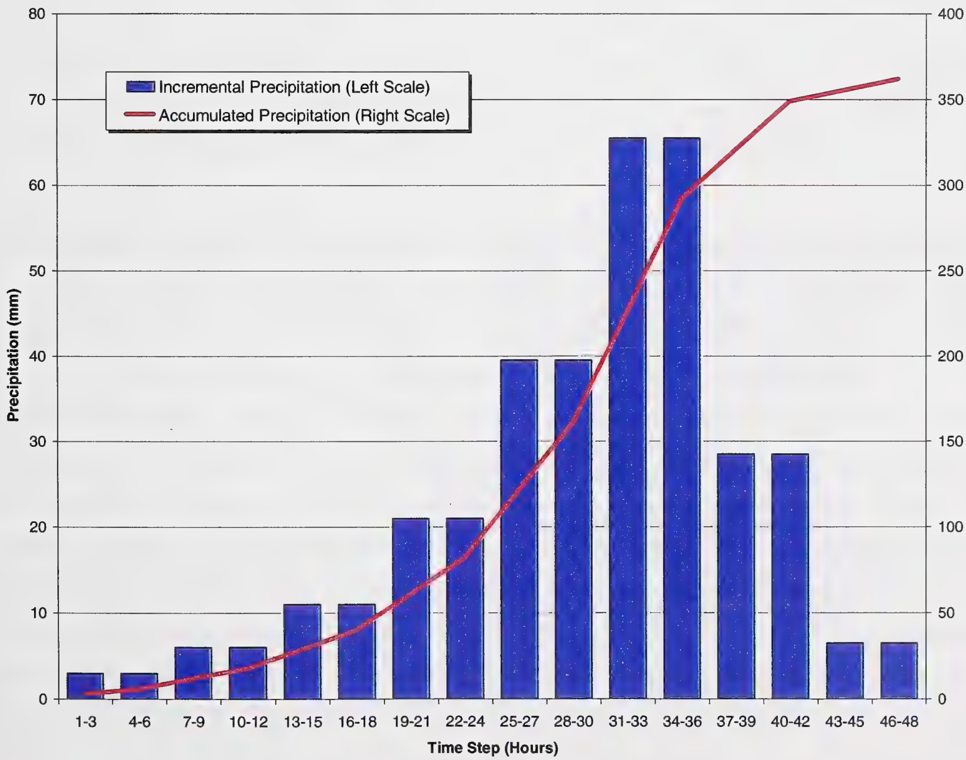


Table 5.1 Critical Rainfall Mass Curve Depth Rankings.

Hours	0-6	7-12	13-18	19-24	25-30	31-36	37-42	43-48
PMP Depth Ranking	8	7	5	4	2	1	3	6
Incremental PMP (mm)	6	12	22	42	79	131	57	13
Accumulated PMP (mm)	6	18	40	82	161	292	349	362

5.2 Estimated PMF

Following general good practice and WMO guidelines, the PMF was simulated using an extended simulation period prior to the application of the PMP. This allows the basin conditions to initialize in a reasonable and realistic manner. Data from 1989, which is the event of record for the Paddle River basin, was chosen to initialize the watershed parameters. Refer to Appendix 3 for a printout of the data file used for the PMF simulation. The critical PMP distribution was applied 90 hours after the occurrence of the August 3, 1989 flood peak, which is considered to be of the order of a 1:100 year event. This corresponds to the approximate conclusion of the surface runoff phase of the 1:100, and is consistent with WMO guidelines that suggest a roughly 72-hour waiting period from the 1:100 peak. This procedure ensures that the basin is "primed" for the PMP.

The starting conditions for the PMF as described above give an initial streamflow of 15.1 m^3/s (532 cfs) and antecedent basin moisture content of 62% (or roughly 5 inches saturated out of an 8 inch soil column). The resulting PMF has a peak of 1,890 m^3/s (66,700 cfs), which works out to a peak yield of 3.05 $m^3/s/km^2$ (279 cfs/sq.mi.). The PMF simulation is shown graphically in Figure 5.2 and is also presented in Appendix 5 with the individual flow components indicated separately. The time to peak is 26 hours as measured from the centre of mass of the PMP, which occurs 31 hours into the 48-hour event. The duration of the runoff event is roughly 168-hours (7 days), with a total hydrograph volume of 198,000 dam^3 (161,000 ac-ft). This translates to a hydrograph runoff depth over the basin of 320 mm. After accounting for the initial baseflow going into the PMP event, it is determined that roughly 48 mm of the 362 mm PMP is abstracted, resulting in a runoff percent nearly 87% for the total PMP. The PMF hydrograph is shown in detail in Figure 5.3.

Figure 5.2 Plot of PMF Model Run Using Calibrated 1989 Model to Establish Initial Conditions.

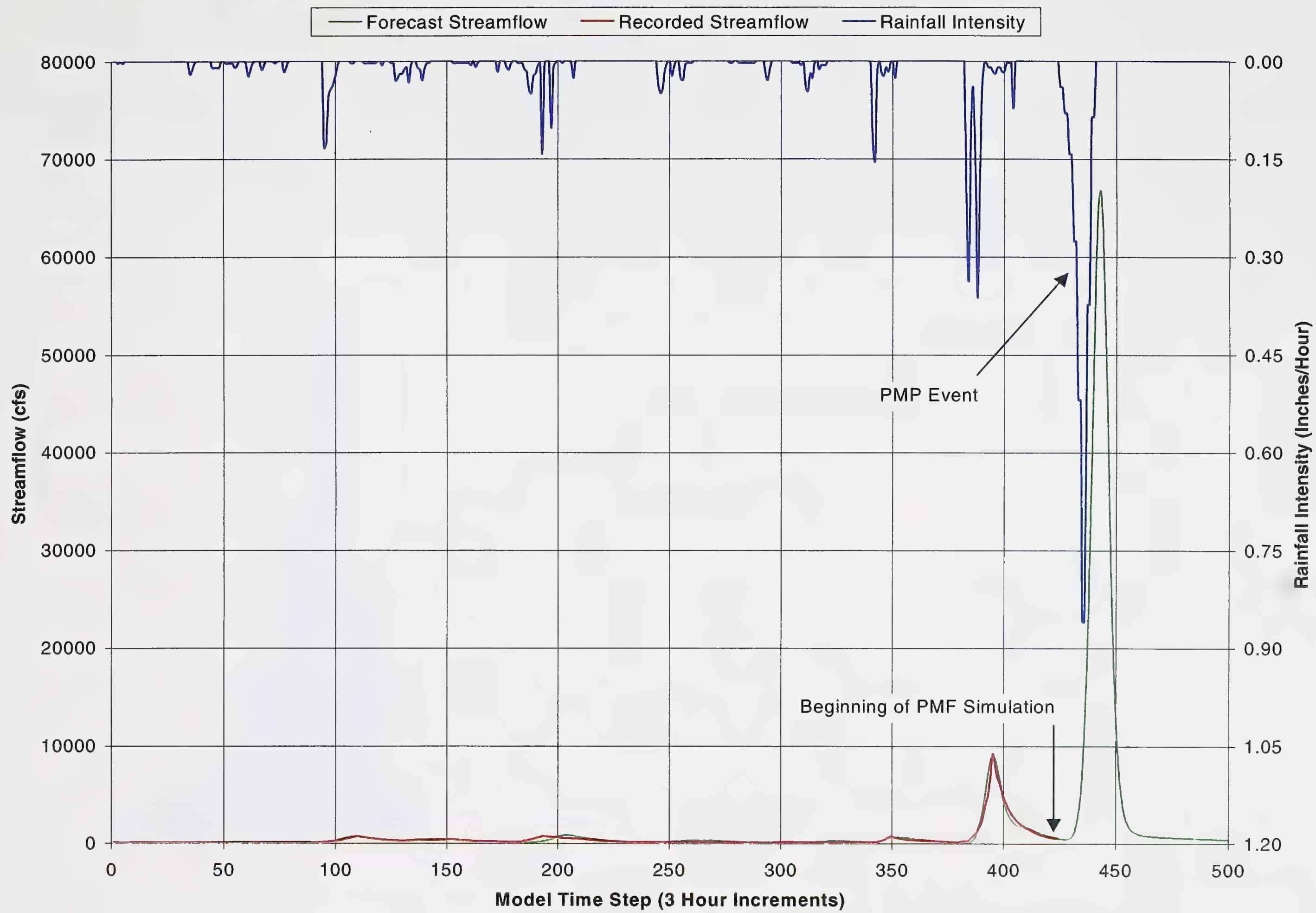
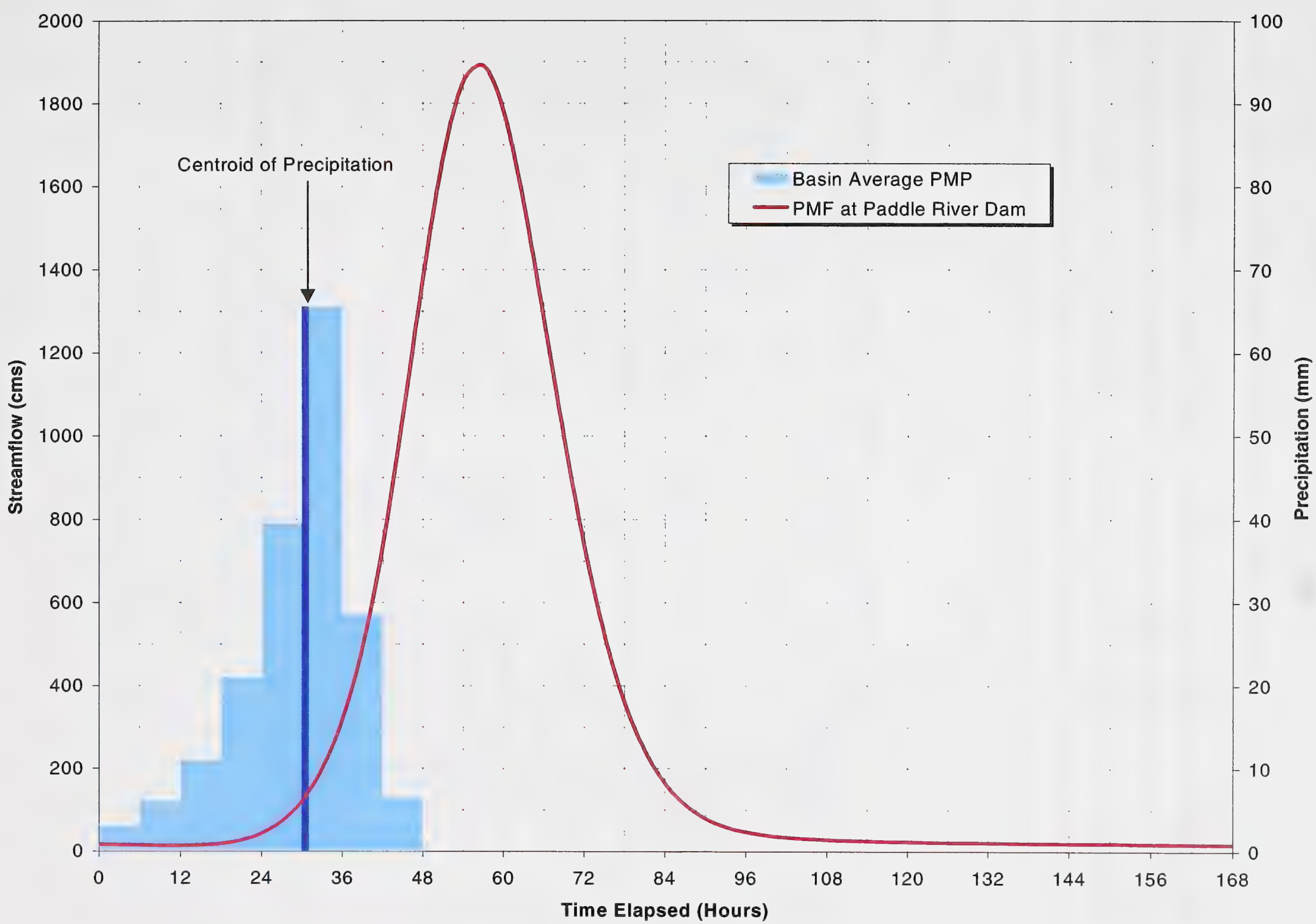


Figure 5.3 Detail of PMF Hydrograph.



6.0 PMF COMPARISON AND DISCUSSION

6.1 Comparison of Estimated PMF to 1985 Value

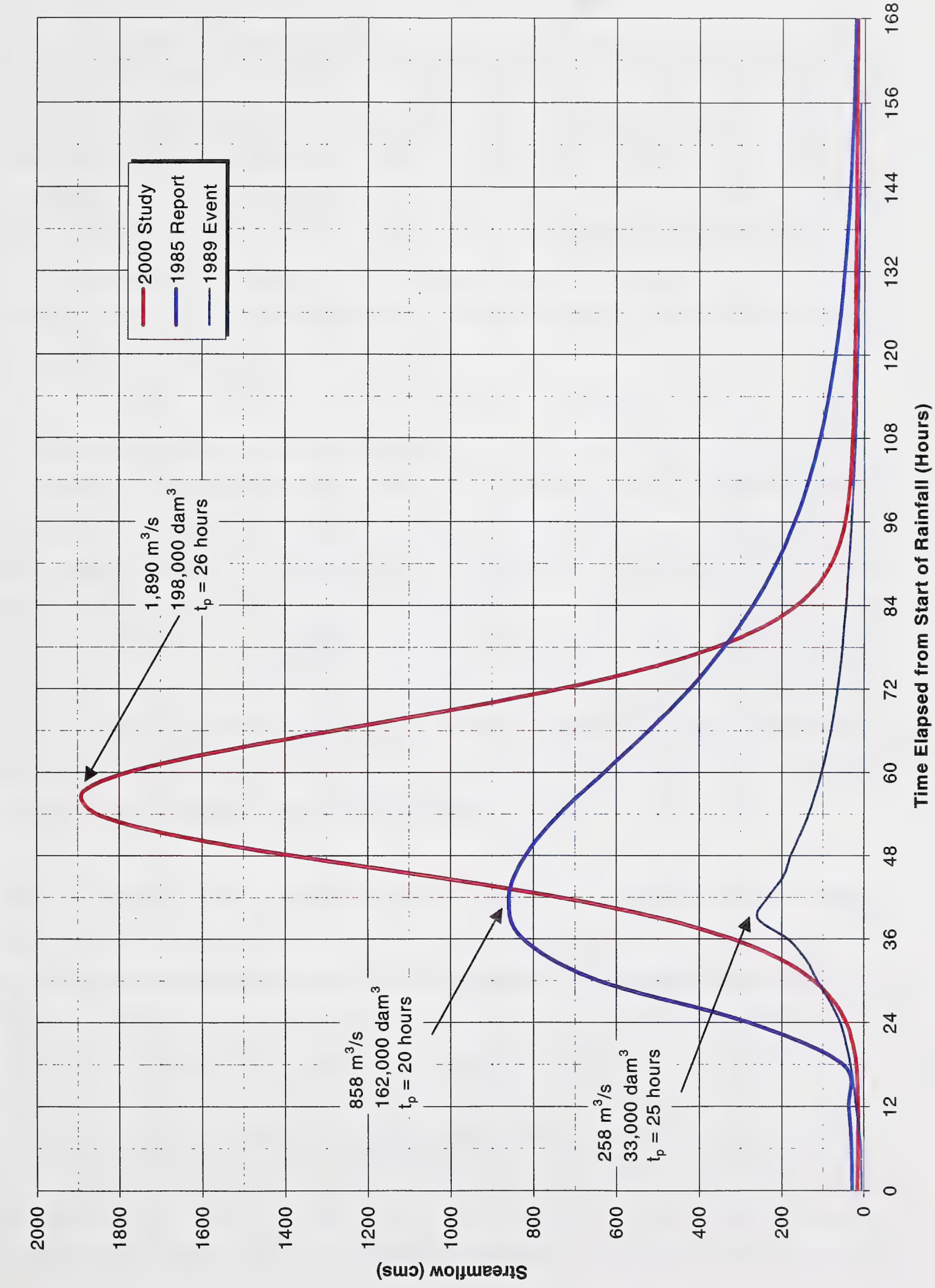
There is a significant difference from the PMF that was previously estimated in 1985 to the value that is presented in the 2000 PMF Study. The present study has determined a PMF peak that is 120% higher and a hydrograph volume that is 22% larger than the previously determined hydrograph. Such a large departure in estimates requires further examination to explain the cause of such differences and to justify the revised figure. Table 6.1 shows the relevant statistics for both studies. The two PMF hydrographs are also illustrated in Figure 6.1, along with the back-routed 1989 event as a comparison.

Table 6.1 Summary-Comparison of 1985 PMF and 2000 PMF Study.

Parameter	2000 Study	1985 Report
Total Precipitation/PMP (mm)	362	344
Centroid of Precipitation (hours)	31	22
Initial Soil Moisture (inches; %)	5.0 / 8.0 (62%)	3.0 / 5.0 (60%)
Initial Baseflow (m^3/s)	15.1	28.3
Peak Flow (m^3/s)	1,890	858
Time to Peak (hours) [1]	26	20
Peak Yield ($m^3/s/km^2$)	3.05	1.38
168-Hour Hydrograph Volume (dam^3)	198,000	162,000
168-Hour Total Runoff Depth (mm)	320	262
168-Hour PMP Runoff Depth (mm) [2]	314	249
Runoff Percent of PMP [3]	86.7	72.4

1. Time to peak is measured from the centre of mass of the PMP to the event peak.
2. As calculated by removing the initial baseflow contribution out of the total runoff depth. Thus, the runoff attributable solely to the PMP input is determined.
3. As calculated by dividing PMP runoff depth by total precipitation.

Figure 6.1 Comparison of PMF Hydrographs.



6.2 Discussion and Justification of Updated PMF

The original PMF Study completed in 1985 followed similar procedures in the computation of the PMP and the modelling of the PMF. Both reports used a precipitation maximization procedure to provide the largest probable precipitation event, and both reports used SSARR modelling to shape the response of the PMF hydrograph. The 1985 PMF assumed a set of initial conditions, rather than running the model ahead of the PMF to initialize the watershed parameters, however, those initial values (such as antecedent soil moisture) appear to be similar in both cases. Therefore, if the increase cannot be attributed to differences in methodology, one must conclude that there are other causes of the large difference observed between the two values.

The final PMP estimates in the two studies are 344 mm and 362 mm, an increase of only 5%. Although this would have a direct effect on the resulting PMF, the increase is far too small to adequately explain the observed increases in hydrograph peak and volume. It then becomes apparent that the modelling of the watershed response by the SSARR model must constitute the majority of the observed changes in the PMF. The SSARR basin relationships from the previous PMF Study were based on an existing SSARR calibration that was used by the River Forecast Centre of Alberta Environment. At the time, the modelers would not have had the benefit of the 1989 record flood peak to assist in any calibrations, so it is not unexpected that the model would have some difficulty replicating both the peaks and volumes of higher order events.

In terms of discussing the individual SSARR modelling parameters that have changed between the 1985 Study and now, the two largest considerations are the basin routing parameters and the soil moisture-runoff relationships. From the shape of the 1985 hydrograph, it is clear that the characteristics of the hydrograph have changed. The previous PMF peaks sooner, and has a much longer recession limb, although the overall timebase of the hydrograph remains virtually unchanged. The flatter shape seems to be more representative of the smaller to middle order events in the basin that are dominated more by subsurface runoff responses, and reflect a good proportion of the events available for calibration prior to 1985. However, the surface routing component probably does not have enough peakiness to match the observed response of mid to high runoff events such

as 1989 and 1986. This revision would account for much of the increase in the PMF peak in this study.

The other large departure in modelling was the amount of soil moisture available for runoff, as given by the SMI-ROP relationship. The 1985 PMF achieved an overall runoff of about 72% of the PMP, even though soil moisture in the basin reached 100% (5.0 inches) and persisted at the height of the event. Although in reality it is unlikely that 100% runoff would be achieved even at totally saturated conditions, it became apparent in the 2000 calibration that much more runoff was needed to be produced in order to replicate the observed hydrograph volumes. Thus, the updated SMI-ROP relationships (see Appendix 2) approach 100% as the soil moisture reaches saturation conditions, but do not reach 100% until the full SMI depth of 8.0 inches is reached. Note that although the soil moisture never reaches the maximum of 8.0 inches (in fact peaking at 85% soil moisture), the overall runoff percent in the 2000 calibration still reaches almost 87% of the PMP input. This accounts for both the increased hydrograph volume and peak for the 2000 PMF estimate.

The large difference in the present PMF value cannot be attributed solely to any single factor, but rather a combination of factors that all seem to favour an increase in the PMF estimate. Although the procedures used to derive the PMP and the PMF in both cases were similar, the greater length of record available and the occurrence of two large runoff events in the period following the construction of the dam allow for higher confidence and a refinement of the SSARR watershed model to better represent extreme runoff events, such as the PMF.

6.3 PMF Estimate in Comparison to Others

Although Alberta Environment has undertaken several PMF Studies, all of these watersheds have been in the southern portion of the Province, the nearest study area being the Dickson Dam PMF in the Red Deer River basin. Typically, these other studies involved somewhat larger basins and are at higher elevations (with headwaters in the Rocky Mountains) than the Paddle River basin. Direct comparisons, therefore, may not be ideal but are also not unreasonable given our understanding of the general synoptic conditions that give rise to large events in the Mountain-Foothills areas. Keeping these differences in mind, the Paddle

River Dam PMF will be put into the context of not only other PMF studies, but also against other recorded extreme events from Alberta and from throughout Canada.

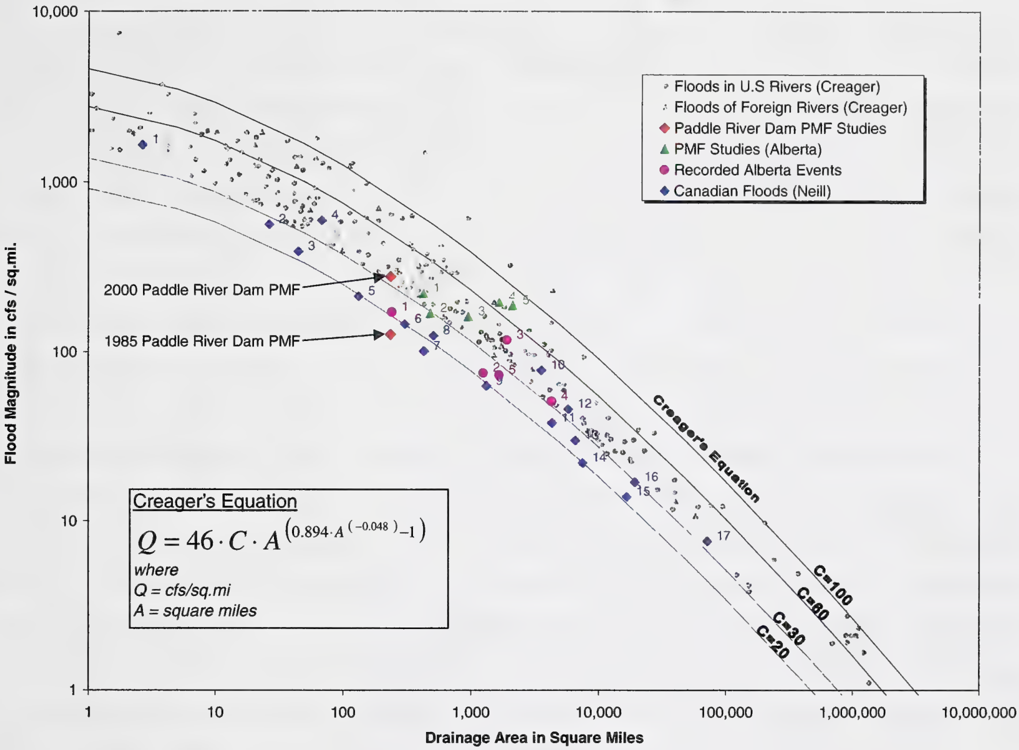
The approach of using flood envelope curves (unit area discharge plotted against contributing drainage area) provides a good visual means of comparing peak flow rates from recorded events against this and other PMF studies. The Creager Diagram revised by Neill (1986) documents many unusual Canadian flood events, and will serve as a baseline for a flood envelope diagram. Table 6.2 contains a listing of those events, plus some additional PMF information and recent data from Alberta events. The relative magnitudes of the 1985 and 2000 PMF estimates for the Paddle Basin have been plotted against this information as shown in Figure 6.2.

Table 6.2 Recorded and Estimated PMF Events Superimposed on Creager Diagram.

Flood Category	Drainage Area (sq.mi.)	Yield (cfs/sq.mi.)
Canadian Floods (Neill)		
1 Harvey Cr. BC, 1969	3	1660
2 Rainy R. at the mouth BC, 1958	27	564
3 Norris Cr. near Dewdney BC, 1984	45	391
4 Zeballos R. near Zeballos BC, 1975	69	596
5 Hirsch Cr. near the mouth BC, 1974	134	213
6 Humber R. at Weston ON, 1954	309	146
7 Castle R. at Cowley AB, 1923	435	101
8 Bay du Nord R. at Big Falls NF, 1983	517	125
9 Explois R. below Stoney Brook NF, 1983	1340	63
10 Iskut R. Below Jonson R. BC, 1961	3610	78
11 Wapiti R. near Grande Prairie AB, 1972	4360	38
12 Arctic Red R. at Martin House NWT, 1970	5840	46
13 Oldman R.at Lethbridge AB, 1908	6640	30
14 Muskwa R. near Fort Nelson BC, 1971	7606	22
15 Fort Nelson R. near Fort Nelson BC, 1971	16800	14
16 Smoky R. at Watino AB, 1972	19400	17
17 Peace R. at Peace River AB, 1965	72000	7.6

Flood Category	Drainage Area (sq.mi.)	Yield (cfs/sq.mi.)
Recorded Alberta Events		
1 Deep Valley Cr. Near Valleyview, 1987	245	172
2 Kakwa R. near Grande Prairie, 1982	1275	75
3 Simonette R. near Goodwin, 1987	1951	118
4 Wapiti R. near Grand Prairie, 1982	4360	51
5 Oldman R. at Oldman Dam, 1995	1698	73
PMF Studies (Alberta)		
1 Willow Cr. near Claresholm	431	222
2 Wateron R. at Waterton Reservoir	488	169
3 Milk R. at Milk R. Dam	970	162
4 Oldman R. at Oldman Dam	1690	198
5 Red Deer R. at Dickson Dam	2150	188
Paddle River Dam PMF Studies		
1 1985 Paddle R. Dam	240	127
2 2000 Paddle R. Dam	240	279

Figure 6.2 Flood Events and PMF Estimates Superimposed on Creager Diagram.



Although the unit yield given in Table 6.2 for the Paddle PMF may appear at first glance to be high in relation to the other PMF studies, it must be remembered that basin yields generally increase as the size of watershed decreases, all other things being equal. This phenomenon is readily apparent when looking at the Creager Plot in Figure 6.2. As was alluded to previously, any strict interpretation of comparisons between Alberta and national or international conditions must be done with some caution as the hydrometeorologic conditions that give rise to extreme events are variable from region to region and can also depend on local conditions. Nevertheless, the 2000 PMF estimate appears to sit well in relation to the other PMF studies and is generally above the range of extreme events that have already been recorded in Alberta and Canada. Conversely, the 1985 PMF estimate appears to be low, sitting somewhat below the observed range of data. These conclusions favour the new PMF estimate and justify the upward revision of the original PMF.

6.4 Potential Impact of Channel Capacity on PMF Derivation

Notwithstanding the evidence that suggests an upward revision to the 1985 PMF peak is fully warranted, it would be remiss if any potentially limiting assumptions were not explored in this report. Although the SSARR model calibration is excellent for the range of flows that it is calibrated to, it is essentially a hydrologic model and therefore assumes that the flow regime will be similar for all flows. This requires an assumption that flows remain confined to the main channel and flood plain area. However, given the topography of the Paddle River watershed and the large magnitude of the PMF peak, it is not entirely certain that this assumption is valid. The typically mild relief and the lack of a deep, incised channel suggest that it would be possible for a large amount of water to spill overbank and create large areas of depression storage. Should this be the case, the peak of 1,890 m^3/s would be somewhat mitigated, although the extent cannot be determined using the methodology of this study. Detailed hydraulic modelling using channel cross-sections and watershed topography would be required in order to determine what effect the channel capacity has, and the resulting impact of the additional storage within the watershed. This type of modelling is outside the area of expertise of the Hydrology/Forecasting Section. If deemed appropriate, the work to potentially further refine the PMF estimate would have to be undertaken by a group possessing such skills and capabilities. In the absence of such detailed information, the PMF estimate contained in this report is considered to be somewhat conservative.

7.0 SUMMARY AND CONCLUSIONS

The Paddle River Dam was completed in 1985 and is designed to act as a flood control structure. Normal outflow is via an outlet conduit under the dam. The spillway is an uncontrolled chute spillway that discharges when reservoir levels reach the crest elevation. The design capacity of the spillway is 800 m^3/s, based on some attenuation of the inflow hydrograph of the Probable Maximum Flood as it is routed through the reservoir. The overall maximum achievable outflow is about 850 m^3/s. The purpose of this study is to assess whether the original estimated PMF of 858 m^3/s remained valid, as part of a larger 5-year review of the structure.

The Probable Maximum Precipitation was derived based on World Meteorological Organization guidelines. This methodology uses two separate components of precipitation, convergence and orographic, to maximize the potential of observed storm events to produce the maximum possible moisture. For this study, the orographic component was not evaluated due to the lack of significant topographic barriers in the basin. The final PMP estimate did not differ materially from the original 1985 report. The average 48-hour PMP for the Paddle River basin above the dam is determined to be 362 mm.

A SSARR model of the basin was calibrated to the highest observed rainfall/runoff events in the watershed. All of these events occurred after the completion of the original PMF Study and after the construction of the dam. The PMP was applied to the watershed model to produce the PMF estimate of inflow to the reservoir. The resulting hydrograph has a peak of 1,890 m^3/s and a 168-hour hydrograph volume of 198,000 dam^3. Although it is possible that the potential effects of storage and overbank flow along the channel could act to mitigate this peak, an assessment of this nature is outside the direct area of expertise of the Hydrology/Forecasting Section. Further detailed hydraulic modelling would be required in order to undertake an analysis of the channel capacity and the resulting impact of channel storage. Under these conditions, this assessment is considered to be conservative.

Climate change scenarios have not been factored into this report. At this point in time, climate change and its potential impact on the PMP and the PMF estimates are not well understood. The hydrologic design component of the structure will continue to be reviewed

as part of the ongoing five-year review process. The need to update the PMF estimate to include climate change considerations is not warranted at this time.

Outlet design changes may be required as a result of the revised PMF estimate contained in this report. Flexibility should be factored into the redesign of the facility, where feasible, to accommodate the potential impacts to the PMF arising from possible climate change in the future.

8.0 REFERENCES

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APPENDIX 1: PERSISTING DEW POINT DATA AND MAXIMIZATION OF THE 1973 STORM

1:100 Year, *X*-Hour Persisting Dew Point Temperatures (°C)

Based on Normally-Distributed Maximum Values for the Specified Period and at each Location

Edmonton Municipal Airport — Elevation: 671 m

	May 1-15	May 16-31	June 1-15	June 16-30	July 1-15	July 16-31	August 1-15	August 16-31	September 1-15	September 16-30
12 Hour	11.8	13.5	16.5	16.6	18.9	19.5	19.0	17.5	15.9	12.6
24 Hour	11.1	13.0	15.9	15.8	18.0	18.3	18.2	16.8	15.1	11.7
36 Hour	10.2	12.6	15.4	15.5	17.8	17.9	18.1	16.4	14.8	11.2
48 Hour	9.3	12.2	14.9	15.2	17.5	17.4	17.8	15.9	14.3	11.0

Whitecourt — Station-Weighted Average Elevation: 759 m

	May 1-15	May 16-31	June 1-15	June 16-30	July 1-15	July 16-31	August 1-15	August 16-31	September 1-15	September 16-30
12 Hour	10.9	12.5	15.7	16.2	18.7	19.3	19.6	17.9	16.0	12.9
24 Hour	9.6	11.9	14.9	15.5	17.5	17.9	18.1	16.7	14.6	11.4
36 Hour	8.9	11.6	14.6	15.0	17.3	17.4	17.7	16.6	14.4	10.9
48 Hour	8.4	11.2	14.2	14.6	16.8	16.8	17.4	16.1	13.7	10.7

Edson (Record Extended Using Edmonton Municipal Airport-Assign a Lower Quality to Data) — Elevation: 925 m

	May 1-15	May 16-31	June 1-15	June 16-30	July 1-15	July 16-31	August 1-15	August 16-31	September 1-15	September 16-30
12 Hour	11.1	11.4	14.8	14.8	16.8	18.0	17.6	17.2	14.9	11.5
24 Hour	10.2	11.1	14.1	14.0	15.9	17.1	17.3	15.9	14.0	9.3
36 Hour	9.8	10.7	13.7	13.9	15.8	17.2	16.6	16.0	14.2	9.8
48 Hour	8.7	10.3	13.4	13.9	15.5	16.6	16.4	15.5	13.7	9.5

Reduced to 1000-mb, Elevation 0m

Edmonton Municipal Airport — Elevation: 671 m

	May 1-15	May 16-31	June 1-15	June 16-30	July 1-15	July 16-31	August 1-15	August 16-31	September 1-15	September 16-30
12 Hour	15.1	16.5	19.4	19.6	21.7	22.2	21.7	20.3	18.9	15.7
24 Hour	14.4	16.1	18.9	18.8	20.9	21.1	21.1	19.7	18.0	14.9
36 Hour	13.6	15.8	18.4	18.5	20.6	20.7	20.9	19.3	17.7	14.4
48 Hour	12.8	15.4	17.8	18.2	20.4	20.3	20.7	18.9	17.3	14.3

Whitecourt — Station-Weighted Average Elevation: 759 m

	May 1-15	May 16-31	June 1-15	June 16-30	July 1-15	July 16-31	August 1-15	August 16-31	September 1-15	September 16-30
12 Hour	14.7	16.0	19.1	19.6	21.8	22.4	22.6	21.1	19.4	16.4
24 Hour	13.5	15.6	18.3	18.9	20.7	21.1	21.3	20.1	18.0	15.1
36 Hour	12.9	15.3	18.0	18.4	20.6	20.7	21.0	19.9	17.8	14.7
48 Hour	12.4	14.9	17.6	18.0	20.2	20.1	20.7	19.5	17.1	14.4

Edson (Record Extended Using Edmonton Municipal Airport-Assign a Lower Quality to Data) — Elevation: 925 m

	May 1-15	May 16-31	June 1-15	June 16-30	July 1-15	July 16-31	August 1-15	August 16-31	September 1-15	September 16-30
12 Hour	15.9	15.7	19.0	19.1	20.9	22.0	21.5	21.2	19.0	15.8
24 Hour	15.2	15.6	18.4	18.3	20.1	21.2	21.3	20.1	18.1	13.9
36 Hour	14.8	15.3	18.0	18.1	20.0	21.4	20.6	20.1	18.3	14.5
48 Hour	13.8	14.8	17.7	18.1	19.7	20.9	20.6	19.7	17.8	14.2

Average 1:100 Year, *X*-Hour Persisting Dew Point Temperatures (°C)
At 1000-mb, Elevation 0m

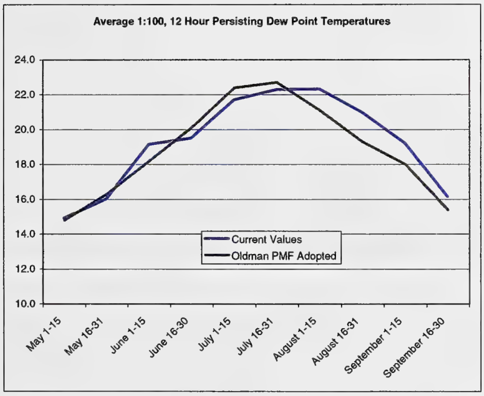
Method 2: Weighted Average Based on Inverse of Distance and Modified for Lesser Data Quality (Edson)

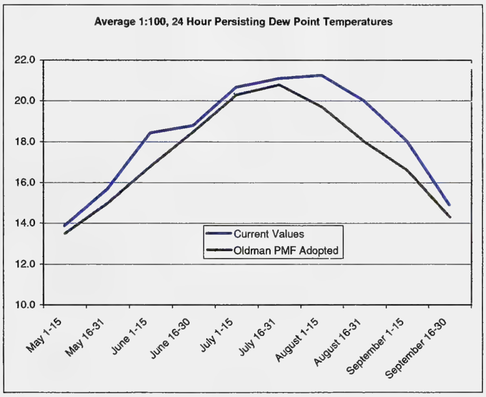
Station	Approx. Distance	1/D	Weight	"Quality"	Final Weight
Edmonton Municipal	128 km	0.007813	0.159	100%	0.187
Whitecourt	35 km	0.028571	0.581	100%	0.683
Edson	78 km	0.012821	0.261	50%	0.130

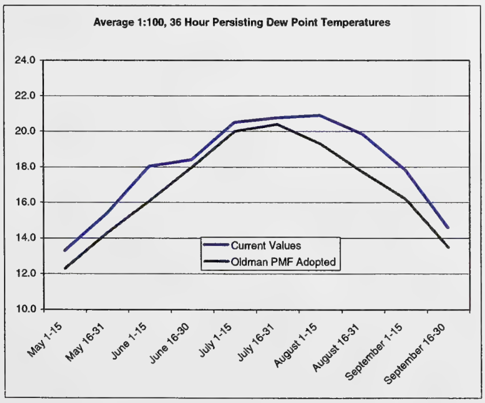
	May 1-15	May 16-31	June 1-15	June 16-30	July 1-15	July 16-31	August 1-15	August 16-31	September 1-15	September 16-30
12 Hour	14.9	16.0	19.2	19.5	21.7	22.3	22.3	21.0	19.2	16.2
24 Hour	13.9	15.7	18.4	18.8	20.7	21.1	21.3	20.0	18.0	14.9
36 Hour	13.3	15.4	18.0	18.4	20.5	20.8	20.9	19.9	17.8	14.6
48 Hour	12.7	15.0	17.6	18.1	20.2	20.2	20.7	19.4	17.2	14.4

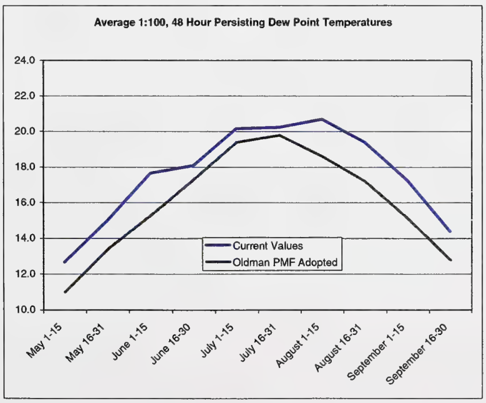
As Adopted in Oldman PMF

	May 1-15	May 16-31	June 1-15	June 16-30	July 1-15	July 16-31	August 1-15	August 16-31	September 1-15	September 16-30
12 Hour	14.8	16.3	18.2	20.1	22.4	22.7	21.1	19.3	18.0	15.4
24 Hour	13.5	15.0	16.8	18.5	20.3	20.8	19.7	18.0	16.6	14.3
36 Hour	12.3	14.3	16.1	18.0	20.0	20.4	19.3	17.7	16.2	13.5
48 Hour	11.0	13.4	15.3	17.3	19.4	19.8	18.6	17.2	15.1	12.8









Maximization of 1973 Storm (Center A) - June 14 to June 17, 1973
(Reference: Oldman PMF Study)
Paddle River Dam Drainage Area = 620 km^2 or 240 sq.mi

		Depth-Area-Duration (mm)				
Area (sq.mi)	Area (km^2)	6 hr	12 hr	24 hr	39 hr (storm)	
100	259	77.72	124.97	190.25	217.93	
200	518	77.27	123.70	188.00	215.90	
240	*620*	*76.95*	*123.40*	*187.49*	*215.40*	*(est.)*
300	777	76.45	122.94	186.70	214.63	
400	1036	76.20	121.92	185.42	213.36	
500	1295	75.18	121.41	184.40	212.09	
600	1554	74.93	120.90	183.64	211.33	
700	1813	74.42	120.40	182.88	210.06	
800	2072	74.17	119.38	181.61	208.28	
900	2331	73.66	118.11	180.59	206.76	
1000	2590	73.14	116.84	179.58	205.23	
2000	5180	67.31	108.46	165.61	189.99	

Statistics of Upwind Meteorologic Stations	Vermilion	Coronation
Elevation (m.asl)	619	717
Pressure (mb)	942	930
Recorded 12 hr Persisting Dew Point (°C)	12.2	11.7
Recorded 12 hr Persisting Dew Point @ 1000 mb (°C)	15.3	15.7

Average 1000 mb, 12 hr Persisting Dew Point for Upwind Stations		15.5 °C
Maximum 1:100 year, 1000 mb, *X* hr Persisting Dew Point (for June 14 to June 17, +/- 15 days about storm)	12 hr	21.7 °C
	24 hr	20.7 °C
	36 hr	20.5 °C
Average Pressure Level of Storm Area		935 mb

Storm Maximization Ratios

Precipitable Water at 15.5°C and 300 mb	34.5 mm
Precipitable Water at 15.5°C and 935 mb	7.0 mm
	27.5 mm

12 hr Maximization

Precipitable Water at 21.7°C and 300 mb	60.5 mm
Precipitable Water at 21.7°C and 935 mb	10.3 mm
	50.2 mm

12 hr Maximization Ratio = 50.2 / 27.5 = **1.83**

24 hr Maximization

Precipitable Water at 20.7°C and 300 mb	55.5 mm
Precipitable Water at 20.7°C and 935 mb	9.8 mm
	45.7 mm

24 hr Maximization Ratio = 45.7 / 27.5 = **1.66**

36 hr Maximization

Precipitable Water at 20.5°C and 300 mb	54.5 mm
Precipitable Water at 20.5°C and 935 mb	9.7 mm
	44.8 mm

36 hr Maximization Ratio = 44.8 / 27.5 = **1.63**

1000 mb Transposition Ratio

Precipitable Water at 21.7°C and 300 mb	60.5 mm
Precipitable Water at 21.7°C and 1000 mb	0.0 mm
	60.5 mm

Precipitable Water at 21.7°C and 300 mb	60.5 mm
Precipitable Water at 21.7°C and 935 mb	10.3 mm
	50.2 mm

1000 mb Transposition Ratio = 60.5 / 50.2 = **1.21** *

* transposition ratio will be applied to all durations

Maximization and Transposition Ratios

12 hr Duration = 1.83 x 1.21 = 2.20

24 hr Duration = 1.66 x 1.21 = 2.00

36 hr Duration = 1.63 x 1.21 = 1.96

Maximized by Variable Maximization Ratio and Tranposed to 1000 mb

		Depth-Area-Duration (mm)				
Area (sq.mi)	Area (km^2)	6 hr	12 hr	24 hr	39 hr (storm)*	48 hr (ext.)
100	259	170.98	274.93	405.68	460.02	
200	518	169.99	272.14	400.92	455.70	
240	***620***	***169.28***	***271.48***	***399.83***	***454.63***	***470.23***
300	777	168.19	270.47	398.17	453.00	
400	1036	167.64	268.22	395.40	450.26	
500	1295	165.40	267.10	393.26	447.62	
600	1554	164.85	265.98	391.63	446.00	
700	1813	163.72	264.88	390.01	443.38	
800	2072	163.17	262.64	387.27	439.63	
900	2331	162.05	259.84	384.98	436.36	
1000	2590	160.91	257.05	382.70	433.06	
2000	5180	148.08	238.61	353.07	400.94	

* based on 36 hr maximum transposition ratio

Maximized by 12-Hour Maximization Ratio (WMO) and Tranposed to 1000 mb

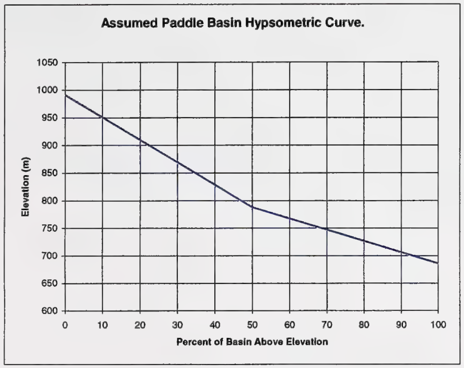
		Depth-Area-Duration (mm)				
Area (sq.mi)	Area (km^2)	6 hr	12 hr	24 hr	39 hr (storm)	48 hr (ext.)
100	259	170.98	274.93	418.55	479.45	
200	518	169.99	272.14	413.60	474.98	
240	***620***	***169.28***	***271.48***	***412.47***	***473.87***	***487.87***
300	777	168.19	270.47	410.74	472.19	
400	1036	167.64	268.22	407.92	469.39	
500	1295	165.40	267.10	405.68	466.60	
600	1554	164.85	265.98	404.01	464.93	
700	1813	163.72	264.88	402.34	462.13	
800	2072	163.17	262.64	399.54	458.22	
900	2331	162.05	259.84	397.30	454.87	
1000	2590	160.91	257.05	395.08	451.51	
2000	5180	148.08	238.61	364.34	417.98	

Depletion of 1000-mb Convergence PMP
(Variable Dew Point Procedure)

	Elevation (ft)	**0**	3250	2750	**2580**	2250
	Elevation (m)	**0**	990	838	**787**	685
Hours	1000mb Pesisting Dew Point Temp.(°C)	PMP Depth (mm)				
		P_{1000}	$P_{elev} = P_{1000} * (T\text{-}x) / T$			
0-6	21.7	**169**	123	129	**131**	136
7-12	21.7	**102**	74	78	**79**	82
13-18	20.7	**74**	54	56	**57**	59
19-24	20.7	**55**	40	42	**42**	44
25-30	20.5	**29**	21	22	**22**	23
31-36	20.5	**17**	12	13	**13**	13
37-42	20.2	**16**	12	12	**12**	13
43-48	20.2	**8**	6	6	**6**	6
Total Storm		**470**	342	358	**362**	376

$P_{elev} = P_{1000} * (T\text{-}x) / T$

1000mb Pesisting Dew Point Temp.(°C)	T @ all elev.	x @ 990 m	x @ 838 m	x @ 787 m	x @ 685 m
21.7	60.5	16.6	14.3	13.5	12.0
21.7	60.5	16.6	14.3	13.5	12.0
20.7	55.5	14.9	13.4	12.8	11.3
20.7	55.5	14.9	13.4	12.8	11.3
20.5	54.5	14.9	13.4	12.8	11.3
20.5	54.5	14.9	13.4	12.8	11.3
20.2	53.0	14.9	13.4	12.8	11.3
20.2	53.0	14.9	13.4	12.8	11.3



T: Total Precipitable Water between 1000-mb and 300-mb Nodal Surface (Source: Oldman PMF)

Dew Point Temp. Degrees Celsius *(Interpolated Values in Italics)*

	19	20	*20.2*	*20.5*	*20.7*	21	*21.7*	22
Water (mm)	48.0	52.0	*53.0*	*54.5*	*55.5*	57.0	*60.5*	62.0

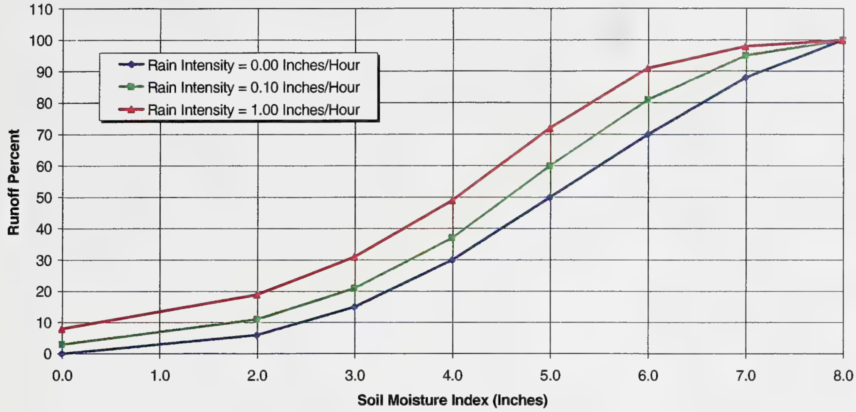
x: Precipitable Water between 1000-mb Surface and Indicated Height (Source: Oldman PMF)

Dew Point Temp. Degrees Celsius *(Interpolated Values in Italics)*

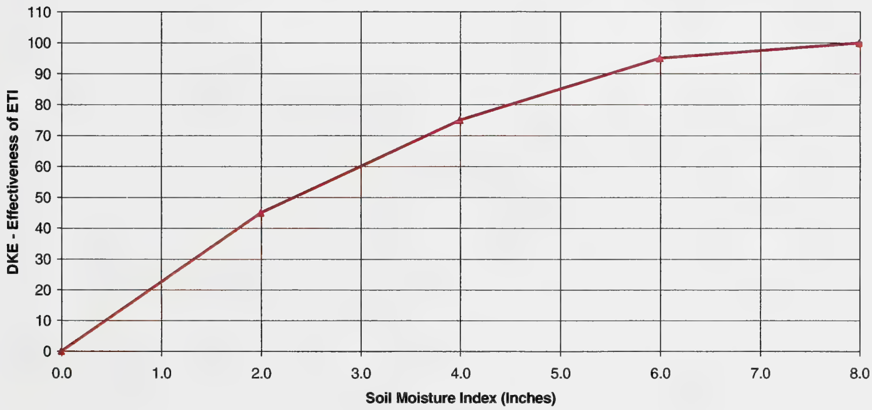
Elev. m	19	20	*20.2*	*20.5*	*20.7*	21	*21.7*	22
400	6.0	6.0	*6.2*	*6.5*	*6.7*	7.0	*7.0*	7.0
600	9.0	10.0	*10.0*	*10.0*	*10.0*	10.0	*10.7*	11.0
685	*10.3*	*11.3*	*11.3*	*11.3*	*11.3*	*11.3*	*12.0*	*12.3*
787	*11.8*	*12.8*	*12.8*	*12.8*	*12.8*	*12.8*	*13.5*	*13.8*
800	12.0	13.0	*13.0*	*13.0*	*13.0*	13.0	*13.7*	14.0
838	*12.4*	*13.4*	*13.4*	*13.4*	*13.4*	*13.6*	*14.3*	*14.6*
990	*13.9*	*14.9*	*14.9*	*14.9*	*14.9*	*15.9*	*16.6*	*16.9*
1000	14.0	15.0	*15.2*	*15.5*	*15.7*	16.0	*16.7*	17.0
1200	17.0	18.0	*18.2*	*18.5*	*18.7*	19.0	*19.7*	20.0

APPENDIX 2: CALIBRATED BASIN RELATIONSHIPS FOR SSARR MODEL

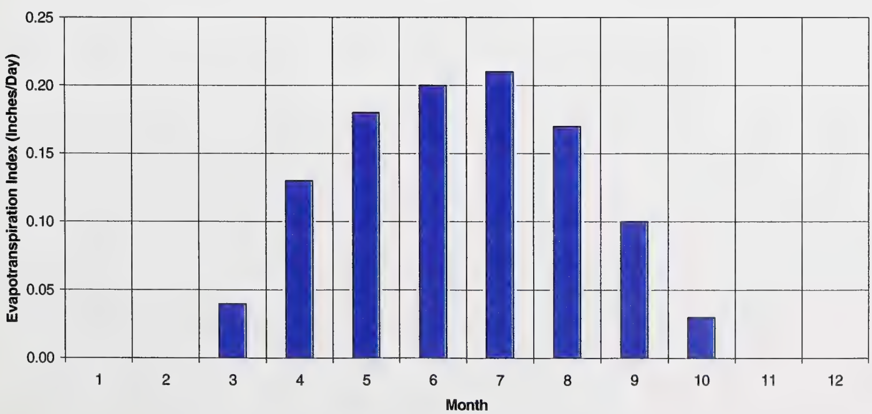
Paddle Basin Soil Moisture Index-Runoff Percent (SMI-RI-ROP) Relationships



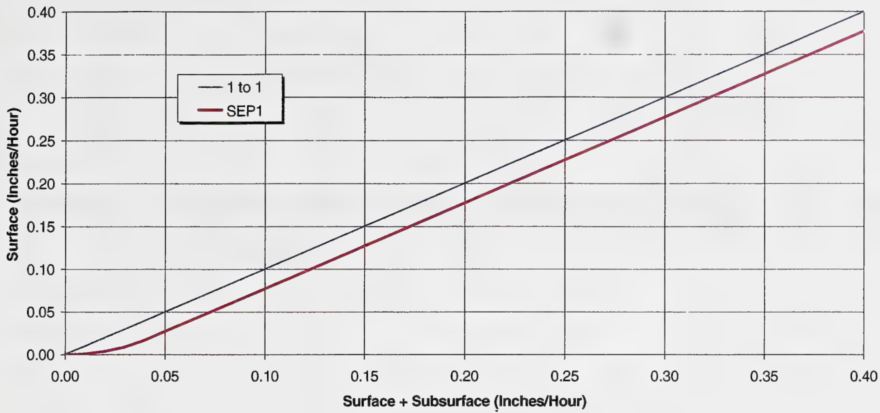
Paddle Basin Soil Moisture Index-ETI Effectiveness (SMI-DKE) Relationship



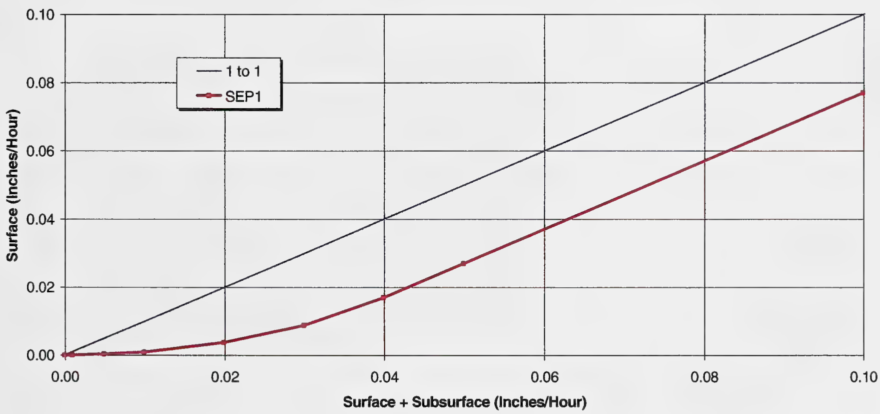
Paddle Basin Evapotranspiration Index (ETI) Values



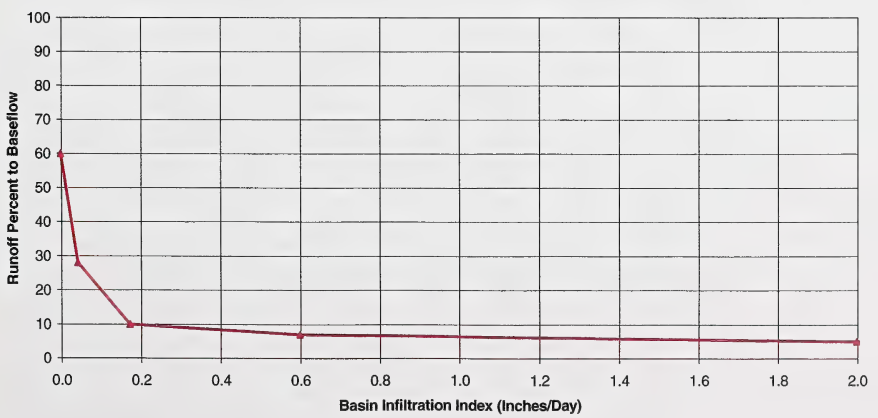
Paddle Basin Surface-Subsurface Separation Relationship



Paddle Basin Surface-Subsurface Separation Relationship (Expanded View)



Paddle Basin Infiltration Index-Runoff Percent (BII-ROP) Relationship



APPENDIX 3: CALIBRATED SSARR MODEL FILE AND PMF DATA FILE

Text Printout of SSARR Model File

```
    ***SSARR MODEL: PADDLE RIVER TO PADDLE RIVER DAM - PMF STUDY OCT 2000
JOB         1100100  11       1         PADDLE RIVER TO PADDLE RIVER DAM

    *** MET STATION IDENTIFICATION - ELEVATION IN FEET ***
CP         PAD2      2613

   *** SMI-RI-ROP RELATIONSHIPS
CF 1       SMP1          .00       .00        0     2.00        6     3.00       15
CF 2       SMP1          .00      4.00       30     5.00       50     6.00       70
CF 3       SMP1          .00      7.00       88     8.00      10099999999      100
CF 4       SMP1          .10       .00        3     2.00       11     3.00       21
CF 5       SMP1          .10      4.00       37     5.00       60     6.00       81
CF 6       SMP1          .10      7.00       95     8.00      10099999999      100
CF 7       SMP1         1.00       .00        8     2.00       19     3.00       31
CF 8       SMP1         1.00      4.00       49     5.00       72     6.00       91
CF 9       SMP1         1.00      7.00       98     8.00      10099999999      100

    *** Alternate BII - BFP TABLE with NO BASEFLOW LIMIT - Use ***
CT 1       BIP2          2.0       0.0       60     .043       28     .174       10
CT 2       BIP2          0.6         7      2.0        5    99999        5

    *** DKE FACTOR ***
CT 1       DKP1            2         0        0        2       45        4       75
CT 1       DKP1            6        95        8      100     9999      100

    *** SURFACE - SUBSURFACE SEPERATION TABLES ***
CT 1       SEP1            2         0        0     .001   .00008     .005    .0004
CT 2       SEP1          .01     .0009      .02    .0038      .03    .0088      .04
CT 3       SEP1        .0170       .05    .0270      .10     .077      .50     .477
CT 4       SEP1          .75      .727     9999     9999

   *** MONTHLY ETI TABLE ***
         *** BASED ON WEIGHTED AVERAGE EDSON/EDMONTON MUN. (ET REPORT)
CT 1       ETI1            2         1        0        2        0        3      .04
CT 2       ETI1            4       .13        5      .18        6      .20        7
CT 3       ETI1          .21         8      .17        9      .10       10      .03
CT 4       ETI1           11         0       12        0

   ***WATERSHED CHARACTERISTICS
CB 1   PDAMBAS         2        PADDLE RIVER DAM BASIN/SFA
CB 2   PDAMBAS    2408  325    952  90    40 DKP1        ETI1SMP1   20
CB 3   PDAMBAS     BIP2  200SEP1             080
CB 4   PDAMBAS     3PAD2100

   ***HYDROMETRIC STATION IDENTIFICATION***
CC 1 FPDAMQIN                   PADDLE DAM INFLOW (FORECAST)
CC 1 RPDAMQIN                   PADDLE DAM INFLOW (RECORDED/SIMULATED)

   ***WATERSHED CONFIGURATION***
N      PDAMPMF
P     RPDAMQIN
P      PDAMBAS  FPDAMQIN
```

Text Printout of SSARR Data File for PMF Simulation

```
                                                            rain_snowmelt__
                                    smi__bii__eti_sca_dsmi    accroaccrototro
                                    XXXxxXXXxx____XXXxXXxx    XXXxxXXXxxXXXxx

2B00 PDAMBAS  030150689        360  001       00 360       000  000  000
2B 4 PDAMBAS  0301506891        26       26       26       26       26       26       26       26
2B 3 PDAMBAS  0301506891         0        0        0        0        0        0        0        0
2B 2 PDAMBAS  0301506891         0        0        0        0        0        0        0        0

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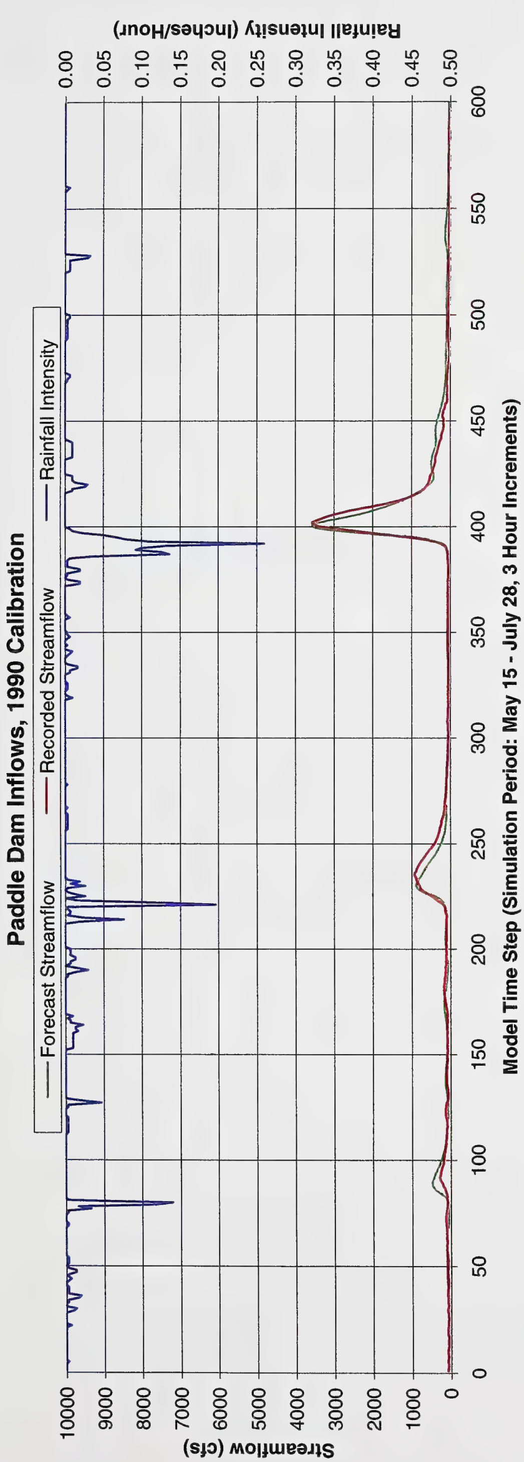
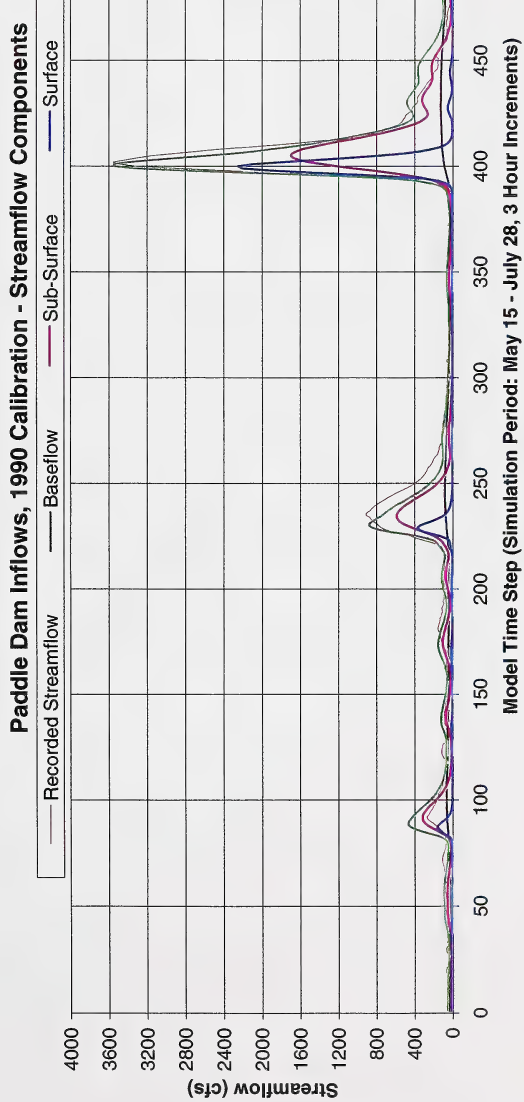
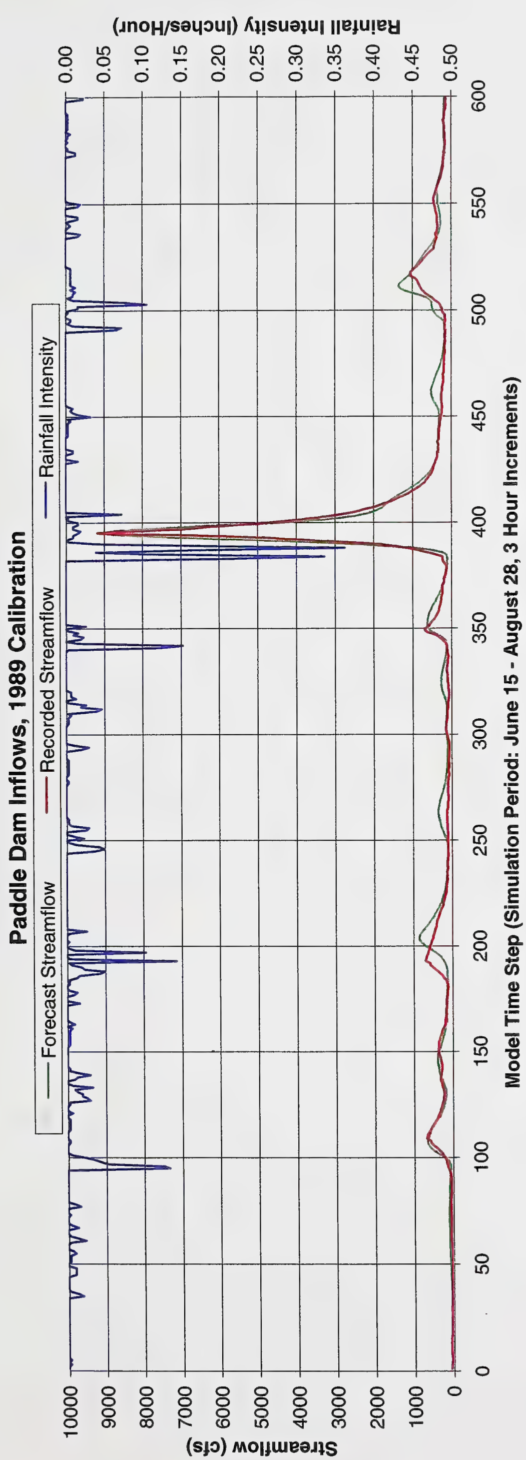
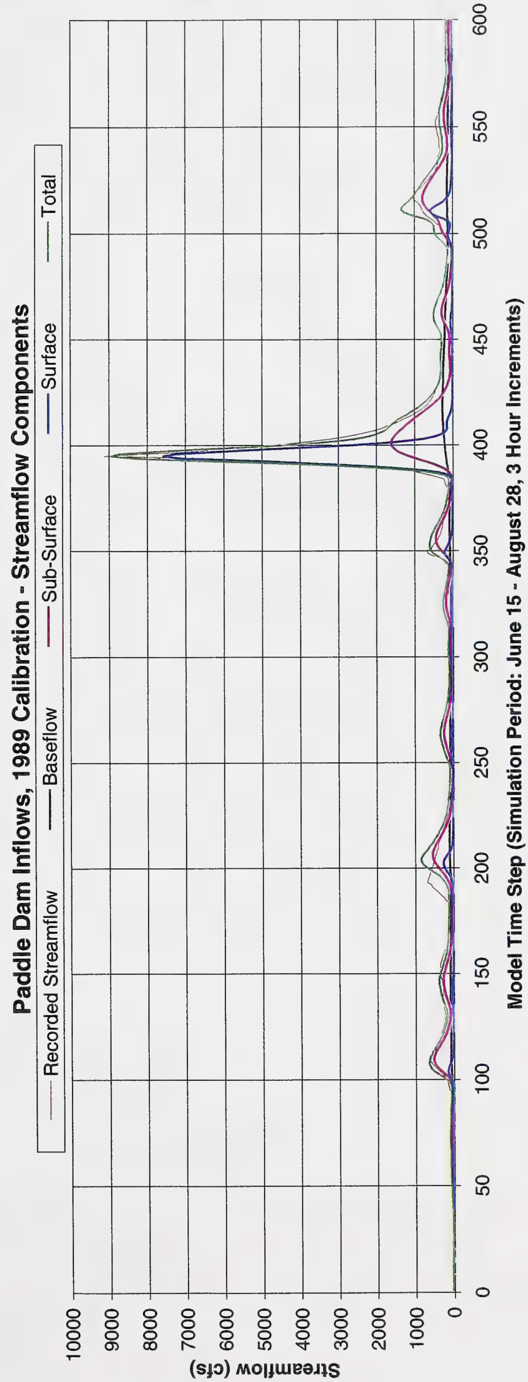
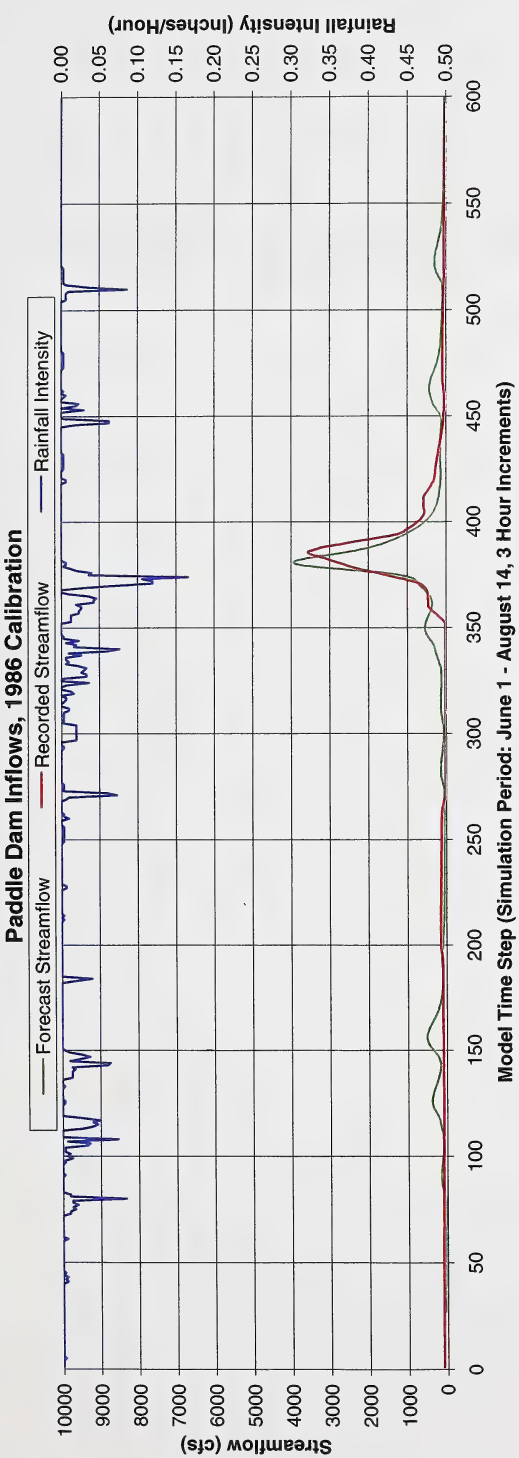
APPENDIX 4: RESULTS OF SSARR MODEL CALIBRATIONS

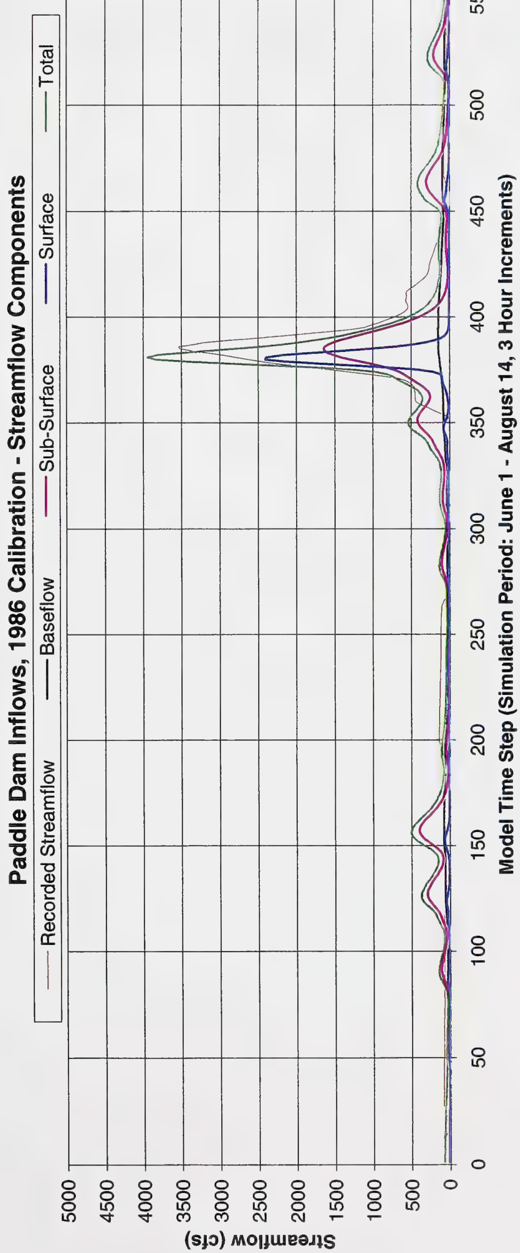

Paddle Dam Inflows, 1990 Calibration
Forecast Streamflow
Recorded Streamflow
Rainfall Intensity
Streamflow (cfs)
Rainfall Intensity (Inches/Hour)
Model Time Step (Simulation Period: May 15 - July 28, 3 Hour Increments)


Paddle Dam Inflows, 1990 Calibration - Streamflow Components
Recorded Streamflow
Baseflow
Sub-Surface
Surface
Total
Streamflow (cfs)
Model Time Step (Simulation Period: May 15 - July 28, 3 Hour Increments)

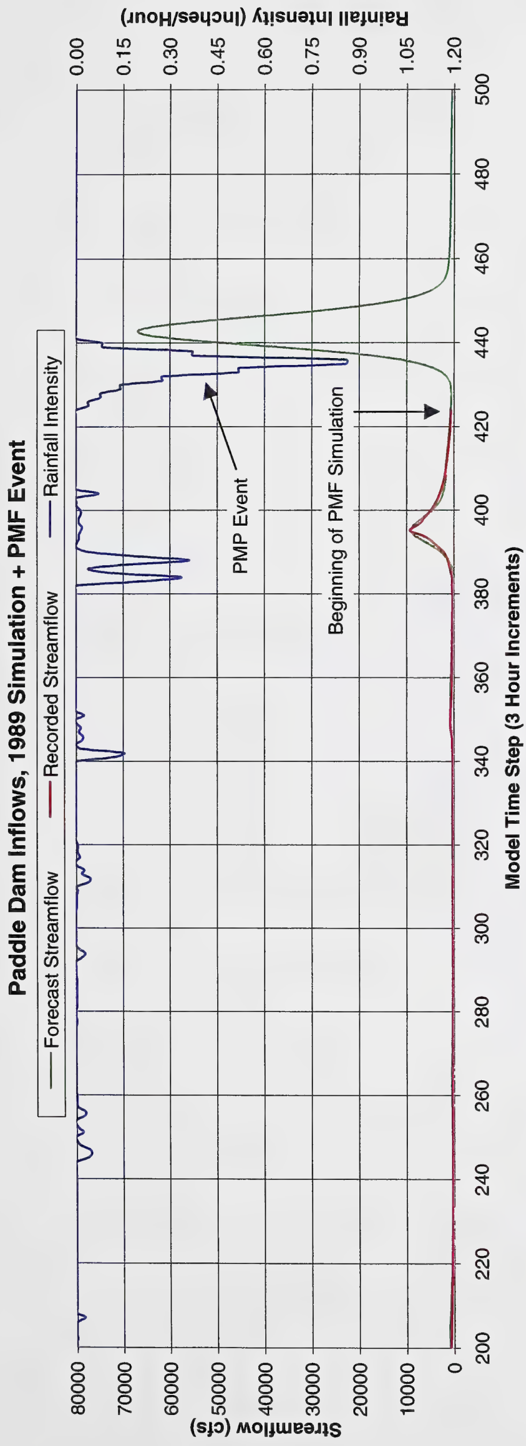

Paddle Dam Inflows, 1989 Calibration
Forecast Streamflow
Recorded Streamflow
Rainfall Intensity
Streamflow (cfs)
Rainfall Intensity (Inches/Hour)
Model Time Step (Simulation Period: June 15 - August 28, 3 Hour Increments)


Paddle Dam Inflows, 1989 Calibration - Streamflow Components
Recorded Streamflow
Baseflow
Sub-Surface
Surface
Total
Streamflow (cfs)
Model Time Step (Simulation Period: June 15 - August 28, 3 Hour Increments)

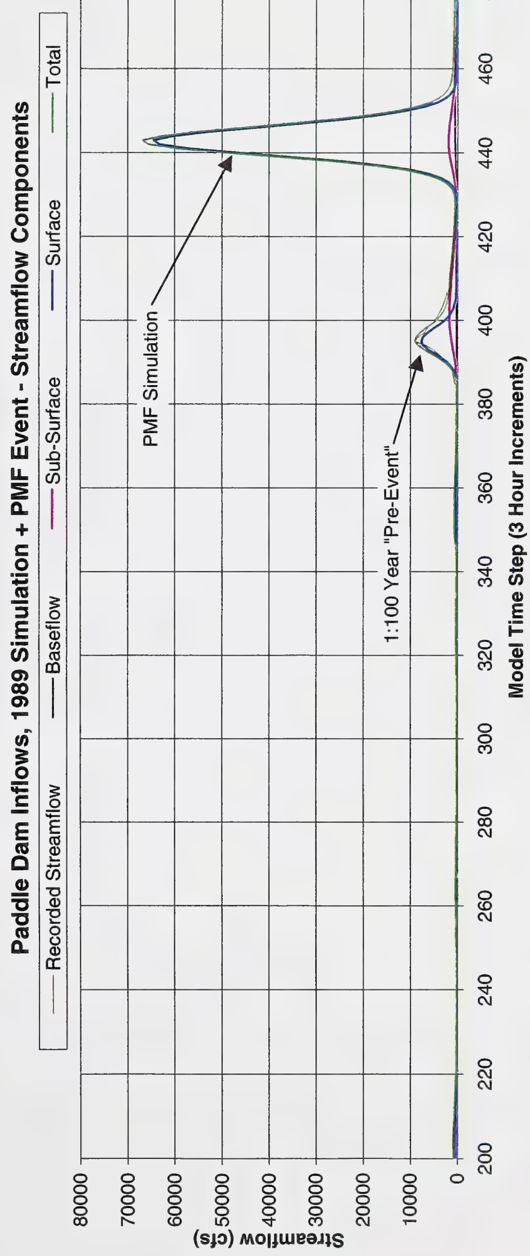

Paddle Dam Inflows, 1986 Calibration
Forecast Streamflow
Recorded Streamflow
Rainfall Intensity
Streamflow (cfs)
Rainfall Intensity (Inches/Hour)
Model Time Step (Simulation Period: June 1 - August 14, 3 Hour Increments)
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.50
0
50
100
150
200
250
300
350
400
450
500
550
600


Paddle Dam Inflows, 1986 Calibration - Streamflow Components
Recorded Streamflow
Baseflow
Sub-Surface
Surface
Total
Streamflow (cfs)
Model Time Step (Simulation Period: June 1 - August 14, 3 Hour Increments)
0
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
0
50
100
150
200
250
300
350
400
450
500
550
600

APPENDIX 5: RESULTS OF SSARR MODEL PMF SIMULATION



Paddle Dam Inflows, 1989 Simulation + PMF Event
Forecast Streamflow
Recorded Streamflow
Rainfall Intensity
PMP Event
Beginning of PMF Simulation
Streamflow (cfs)
Rainfall Intensity (Inches/Hour)
Model Time Step (3 Hour Increments)



Paddle Dam Inflows, 1989 Simulation + PMF Event - Streamflow Components
Recorded Streamflow
Baseflow
Sub-Surface
Surface
Total
PMF Simulation
1:100 Year "Pre-Event"
Streamflow (cfs)
Model Time Step (3 Hour Increments)

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